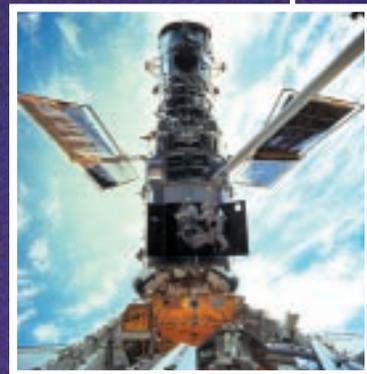
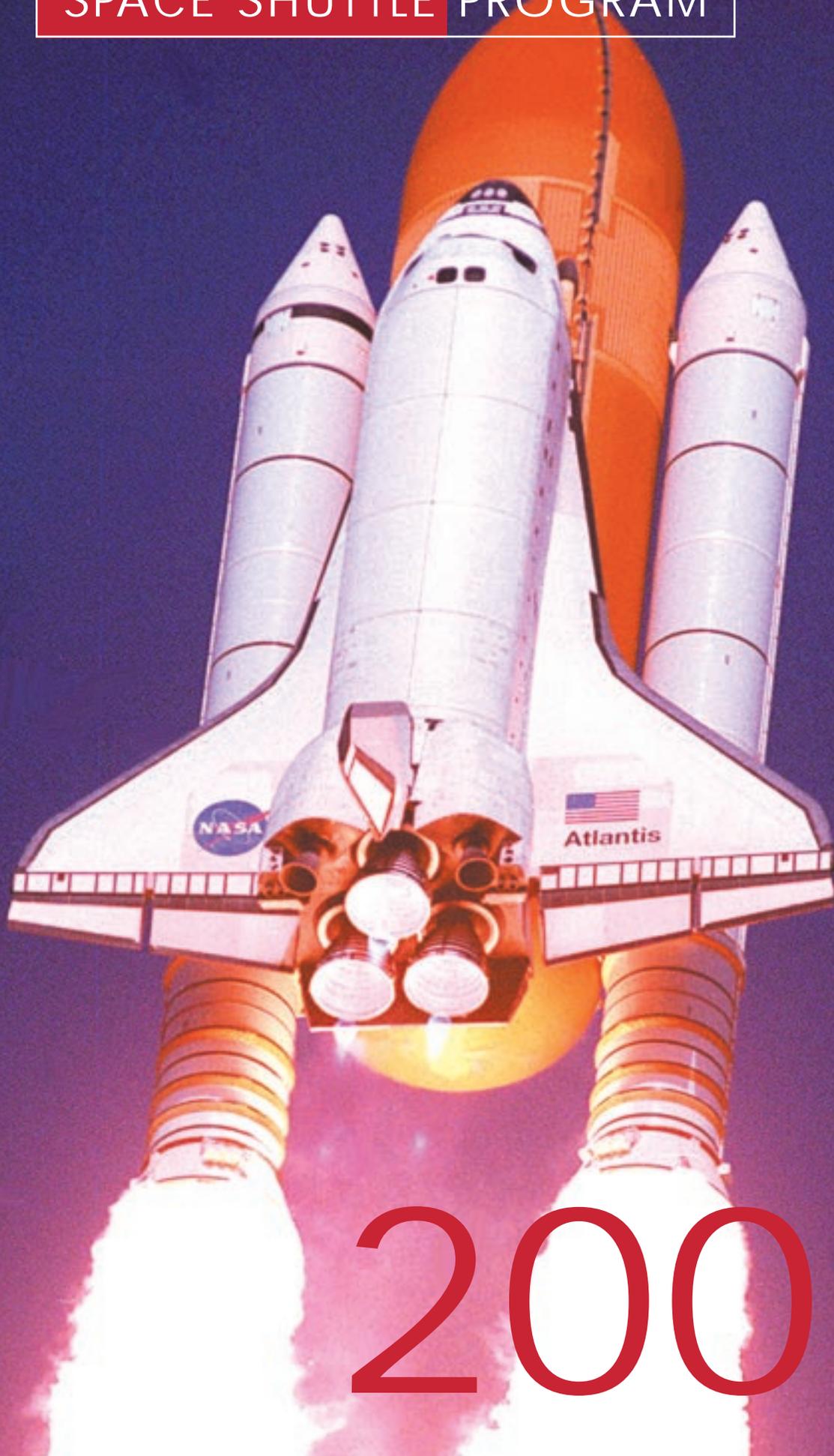


# SPACE SHUTTLE PROGRAM



# 2000

ANNUAL REPORT



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## Message from the Program Manager



**Ronald D. Dittmore**  
Manager,  
Space Shuttle Program (JSC)

This has been an exciting year of hard work and preparation for the Space Shuttle team. We successfully completed five missions, including two successful logistics flights to the International Space Station (ISS) and another that resumed ISS assembly by installing the Z1 Truss

and a second docking port. The third servicing mission to the Hubble Space Telescope was accomplished, allowing the great observatory to continue its stellar accomplishments. STS-99 successfully applied radar topography to map more than 80% of the Earth's land surface in detail 30 times more precise than the best maps previously available.

The team continues to tackle difficult challenges, balancing the need to maintain and upgrade the Space Shuttle fleet while supporting the busy manifest of flights. *Atlantis* completed the inaugural flight of the new glass cockpit and the launch of STS-92 marked the 100th flight of the Space Shuttle Program (SSP). *Columbia* will return from its major modification in early 2001 with *Discovery* scheduled to begin its next major modification in August 2001.

ISS assembly flights and space science missions will require up to 8 missions per year for the foreseeable future. With reduced flight rates in 1999 and 2000, the Program took advantage of this time to concentrate on new ways of meeting the

four SSP goals of flying safely, meeting the manifest, improving mission supportability, and improving the system. Progress in each of these areas has prepared the Program to ramp up for the increased sustained flight rates ahead.

Significant steps were made this year on safety and supportability upgrades for both flight hardware and ground support systems. A Process Control Focus Group was established to raise NASA and contractor awareness to the risks of innocuous process changes that can have far-reaching effects. Efforts to standardize payload interfaces will provide manifesting flexibility on ISS missions, allowing orbiter vehicle swaps late in the flow of launch preparations. Achievements were made to further improve the Program's

*"Instead of worrying about the future, let us labor to create it." – Hubert H. Humphrey*

environmental compliance. Two major initiatives were begun to identify infrastructure

needs and implement industrial engineering improvements with the goal of increasing safety and maintainability.

The most important resources of any program are the people that make it run. Our success rests in the skill and dedication of the SSP team focused on the same goals. This is the core ingredient that sustains the incredible accomplishments that the Program has enjoyed over the years. We have the continued responsibility and the privilege of providing the country and our international partners with safe, reliable human access to space well into the new millennium. The upcoming years will be busy ones, but the SSP team has shown time and again that it is up to the challenge.



# Space Shuttle Program Goals

## **Goal 1 ❖ Fly Safely**

Since returning to flight in 1988, the SSP has had an outstanding safety record and significant progress has been made in improving the reliability of some of its major components. Our goal is to ensure that this legacy continues by investing in upgrades that embrace advanced technologies that improve reliability while assuring safety.

## **Goal 2 ❖ Meet the Manifest**

Meeting the ISS challenge of assembling the most complex space structure ever created requires the SSP to be responsive to mission-specific manifest changes. Space Shuttle planning must be flexible to accommodate the ISS changes while also maintaining the schedules of our non-ISS customers. Along with ISS missions, the Space Shuttle will continue to provide scientific and research missions with continued, reliable human access to space.

## **Goal 3 ❖ Improve Mission Supportability**

The ISS mission requirements place an increased demand on the Space Shuttle systems. The assembly process will require an unprecedented number of extravehicular activities (EVAs), rendezvous and docking, and remote manipulator system activities as well as many other new challenges inherent in a mission of this grand scale. To meet these demands, a series of supportability upgrades are being developed to increase Space Shuttle performance and system capability.

## **Goal 4 ❖ Improve the System**

The SSP has a goal of continuously improving its developmental and operational processes, making them more effective and efficient. The Space Shuttle will fundamentally be the workhorse that builds the ISS. This will require a sustained flight rate to adequately support the assembly sequence. This will be accomplished through a combination of reductions in the flight preparation and postflight hardware refurbishment times, and faster reconfiguration of operational support facilities. As processes are improved and upgrades are incorporated, the Space Shuttle's capabilities will increase, reducing the cost of access to low Earth orbit and providing increased access to the space community.



# Space Shuttle Program Senior Management



**Ronald D. Dittmore**

Manager, Space Shuttle Program (JSC)



**William H. Gerstenmaier**  
Manager  
Program Integration (JSC)



**James D. Halsell**  
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**Alex A. McCool**  
Manager  
MSFC Projects (MSFC)



**Elric N. McHenry**  
Manager  
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**Jack C. Boykin**  
Space Flight Operations  
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**James B. Costello**  
Manager, Business  
Office (JSC)



**William J. Harris**  
Manager, Safety and  
Mission Assurance (JSC)



**Linda J. Ham**  
Special Assistant to SSP  
Manager (JSC)



**Joyce Rozewski**  
Manager, Industrial  
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**Ralph R. Roe**  
Manager, Vehicle  
Engineering (JSC)



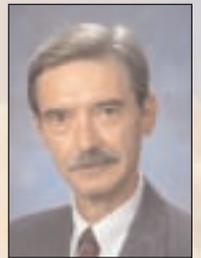
**Lambert D. Austin**  
Manager, Systems  
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**Michele A. Brekke**  
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Flight Integration (JSC)



**Randall L. Segert**  
Manager  
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**Robert H. Heselmeyer**  
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# Space Shuttle Program Council



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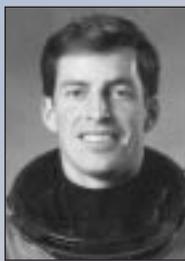


**Randall L. Segert**  
Manager, KSC  
Integration, (KSC)



**Robert H. Hoeselmeyer**  
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SSP Senior  
Management



**James D. Wetherbee**  
Director  
Flight Crew Operations (JSC)



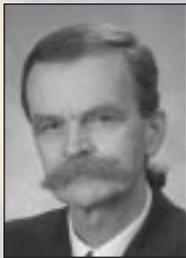
**Jon C. Harpold**  
Mission Operations (JSC)



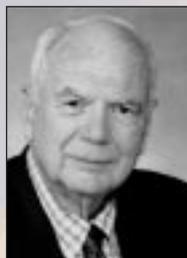
**David A. King**  
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Shuttle Processing (KSC)



**Anne Gawronski**  
Logistics (KSC)



**David A. Hamilton**,  
Chairman, Chief  
Engineers Council (JSC)



**George D. Hopson**  
Manager, Space Shuttle Main  
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**Parker V. Counts**  
Manager, Solid Rocket  
Booster (MSFC)



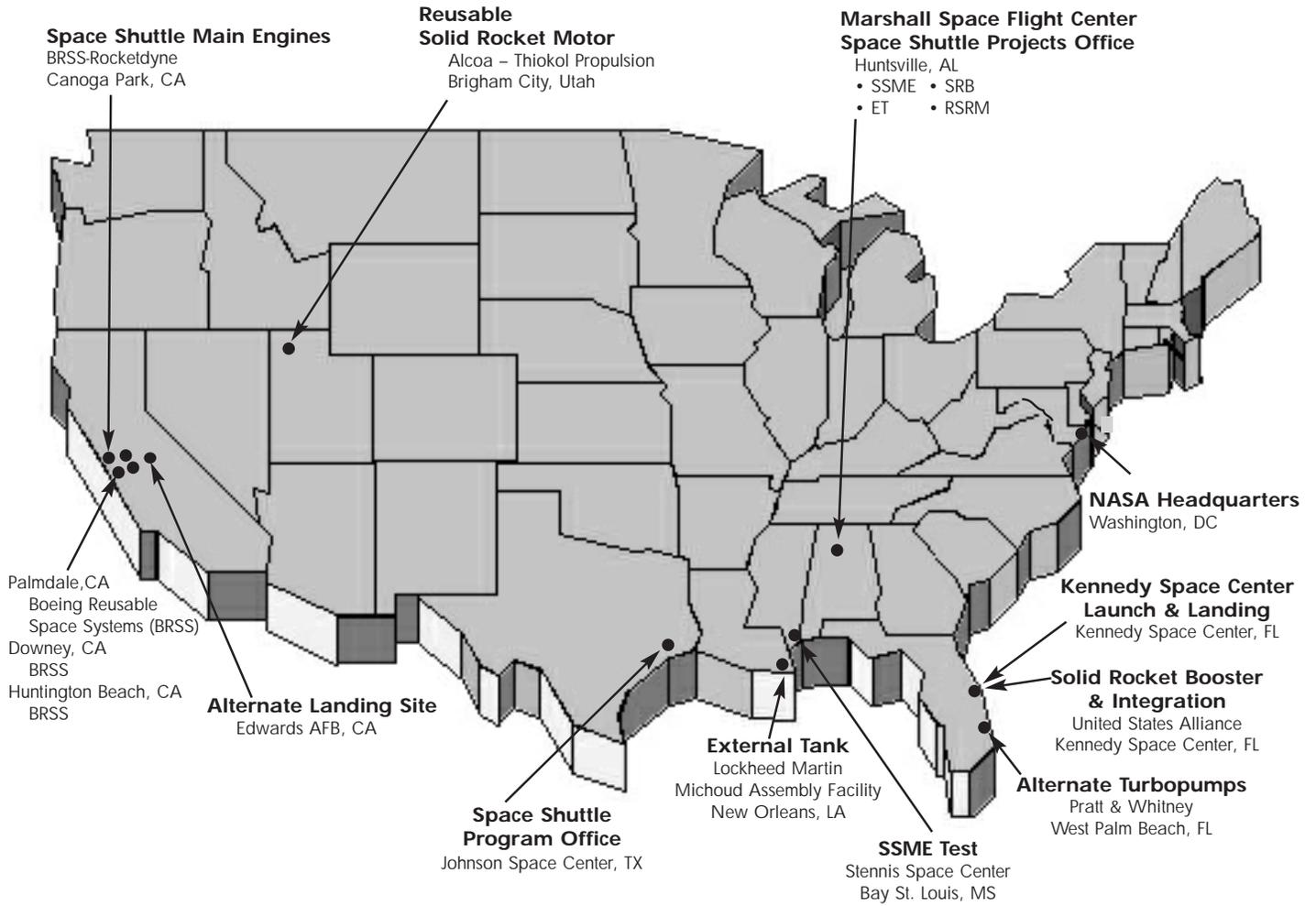
**Michael U. Rudolphi**  
Manager, Reusable Solid Rocket  
Motor (MSFC)



**Jerry W. Smelser**  
Manager  
External Tank (MSFC)



# Space Shuttle Program Major Sites



# Space Shuttle Program Flight History

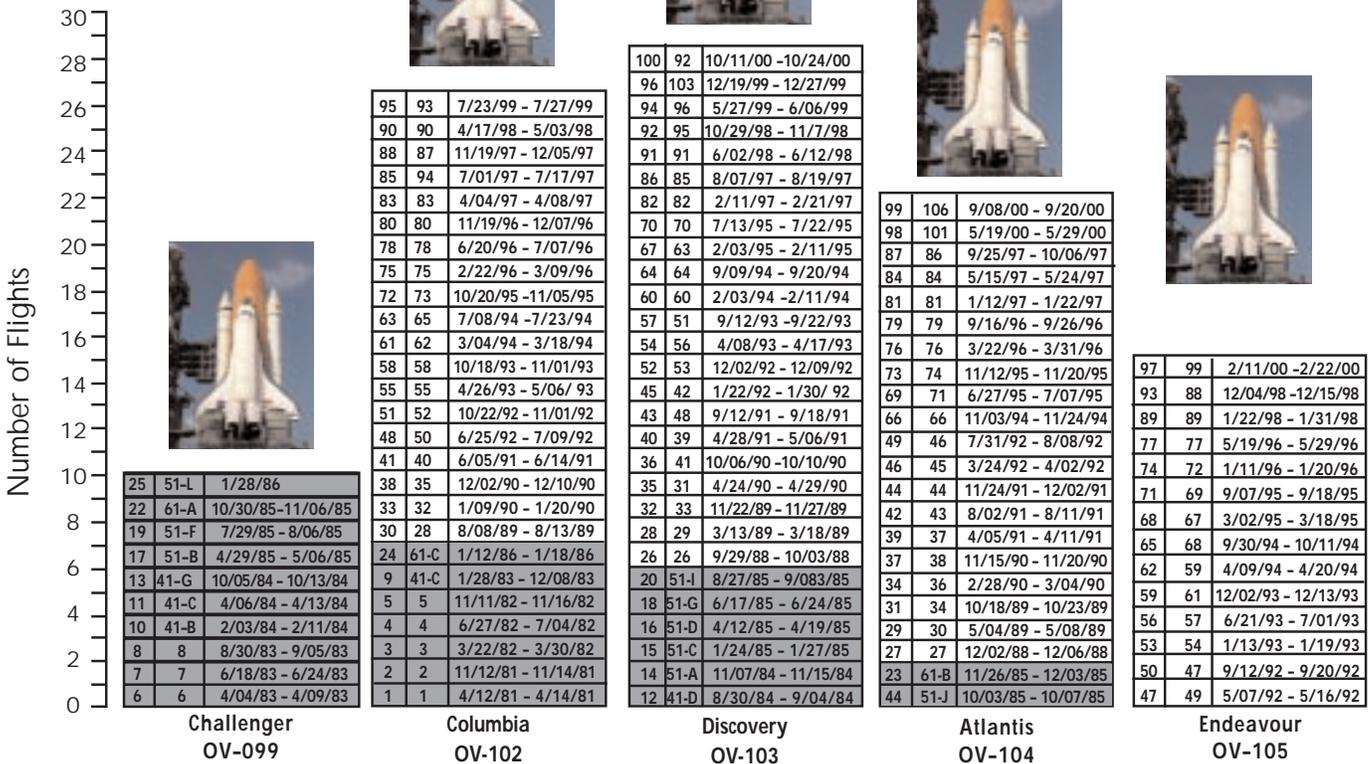
## 100 Total Flights

75 Since Return to Flight

### Legend

Flt. No.	STS-XX No.	Launch Date	Landing Date
----------	------------	-------------	--------------

After 51-L   
 Before 51-L (Flight-25)





# Safety



William J. Harris  
Manager, Safety and  
Mission Assurance (JSC)

## Risk Management

Risk management is an integral element of the overall SSP. The risk management process is structured to integrate Program requirements and procedures in such a way as to ensure potential issues and hazards are identified, analyzed, and mitigated throughout all Program activities. The use of disciplined configuration management of databases, verification and certification processes, use of certified analytical and test techniques, and the use of formal review and acceptance processes form the basis of the SSP risk management process. Timely and effective risk mitigation provides the SSP with high levels of safety, mission success, improved availability/supportability and reduced schedule and costs.

Risk management and the effective identification, assessment, communication and mitigation of risks are continually emphasized by the SSP. A Program Management Review, dedicated exclusively to risk management, was held in March 2000 where NASA and the major SSP contractors presented and discussed their risk management programs and provided an exchange of best practices and lessons learned. The SSP has implemented a set of risk management requirements to provide a centralized focus of the various activities associated with risk management.

## Quantitative Risk Assessment

The SSP is aggressively evaluating quantitative risk assessment methods. A technical interchange meeting was held in August to foster sharing of quantitative techniques across the Program. The System Safety Review Panel has been active in the development and establishment of a standardized quantitative risk assessment process for the SSP. The panel is active with NASA Centers and contractors to establish requirements, tool selection, modeling priorities, and scope for SSP quantitative risk assessment.

## Process Control

Sometimes, small and simple changes, if not properly evaluated, can be negative and destructive. A series of seemingly small but incorrect choices can become little "process-destroying termites" that eat away at the foundations of the process or hardware certification until, before we are aware, we may be brought near to failure and catastrophe.

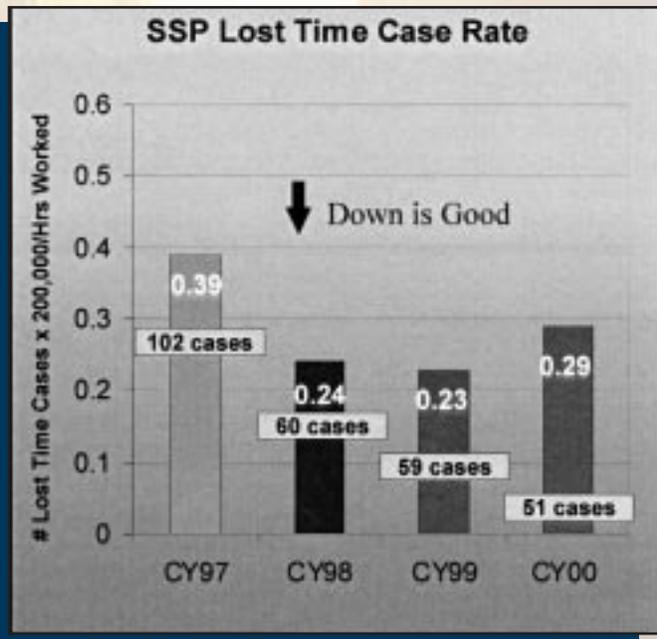
In an effort to raise awareness and prevent these process breakdowns, the SSP chartered a Process Control Focus Group comprising of NASA and contractor managers. This group, in cooperation with the Industrial Engineering for Safety (IES) Initiative, is active in developing proactive methods to preclude process control escapes. The group has produced and distributed Process Control videos and posters and initiated supplier visits by SSP senior management to emphasize the importance of process control.

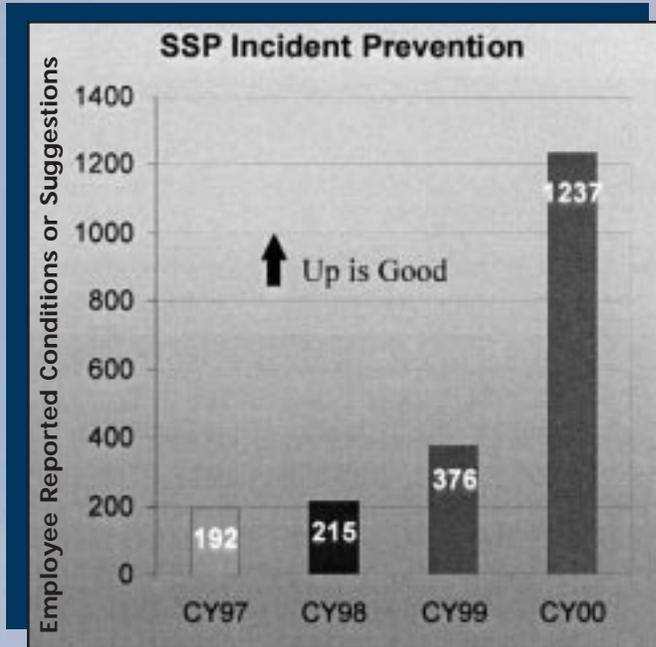


*Recognizing the need to stay focused on safety in the future and applying the Triple A's of safety (Attitude, Accountability, Action) directly contributes to the ultimate success of the Program and ensures a safe work environment for everyone."*

## Safety

Safety continues to be the top priority for the Space Shuttle Team. Management emphasis and employee involvement have led to a number of education and awareness activities involving the total workforce. United Space Alliance (USA) continued to pursue STAR recognition under OSHA's Voluntary Protection Program, certifying 4 additional facilities this year, bringing their total to six. SSP employees have made significant contributions to safety improvements through involvement in various safety committees and working groups and in participation in incident prevention programs such as close call reporting and suggestion programs (see figures).





Senior safety managers representing USA, Boeing-Rocketdyne, Lockheed Martin, Thiokol, and Pratt & Whitney met in the spring and collectively formed the SSP Contractor Safety Council. The Council's charter establishes a technical forum focused on understanding issues that impact programmatic safety performance and identifies initiatives designed to improve performance. At the first meeting, the Council agreed to a common set of safety metrics that are now maintained on a monthly basis and provided to the SSP quarterly. At a second meeting in August, the Council evaluated metrics and developed concepts to reduce hazards and mishaps. An essential aspect of the Council is the ability to identify lessons learned and share best practices across the SSP team. The Council provides a valuable source of experience and subject matter expertise that will result in improved safety for the entire Program.



Joyce Rozewski,  
Manager, Industrial  
Engineering (KSC)

## Industrial Engineering for Safety (IES)

IES is a new, Program-wide safety initiative. This project will apply industrial engineering techniques and analysis such as human factors studies to Space Shuttle processing. The goals are to identify, prioritize, and implement high-value upgrade projects that will reduce risk to the workforce, reduce the risk of collateral damage to flight hardware, and increase maintainability. This will also encourage increased use of industrial engineering methods across the Space Shuttle Program, to ensure that maintainability and human factors elements are adequately considered in new designs. The IES is a planned five-year project with an expected portfolio of evolving content. The portfolio will at any point in time consist of projects in various stages of definition and approval, based on the results of focused human factors studies of Space Shuttle processes. These studies will provide a proactive means of identifying key vulnerabilities that may or may not have surfaced yet as problems.

Some projects fulfilling the goals of the IES initiative are already under way. The orbiter aft hydraulic quick disconnect (QD) modification relocates hydraulic QDs from inside the orbiter aft compartment to the exterior of the orbiter. This will eliminate the potential for accidental collateral damage to hardware caused by people working in the crowded workspace of the aft and inadvertently stepping, leaning, or holding onto critical flight hardware. It will also eliminate a large piece of ground support equipment that restricts personnel access in the aft when it is installed to support the hydraulic QD connection. Also in work are orbiter aft access platform modifications that will improve access to internal and external service areas of the orbiter aft compartment. These modifications were identified by an Aft Protection Process Improvement Team as a top priority in reducing the risk of both personnel injury and damage to critical flight components. The external modifications will improve access to the orbiter liquid oxygen and liquid hydrogen umbilicals and the Space Shuttle Main Engine areas. The internal modifications will improve access to the aft middeck, External Tank sensor lines, and auxiliary power unit and Flash Evaporator System/Main Propulsion System service panels. Over the next year the IES initiative plans to fund additional long-term and short-term projects in order to improve the safety of the workforce and the flight hardware in Space Shuttle processing.



# Resource Management



James B. Costello  
Manager, Business  
Office (JSC)

Fiscal year 2000 (FY 2000) was another extremely successful year for the SSP. Significant resources were applied to Safety Upgrades this year and great progress is being made on these important initiatives to improve the Space Shuttle system. The primary focus was on definition and authorization of the primary Upgrade candidates. Even with additional funds being applied to Upgrades above the 1999 levels, the total SSP costs were below \$3 billion for the second year in a row.

## National Aeronautics and Space Administration Space Shuttle Program Financing and Operations (for the years ending September 30, 1999 and 2000) (In Millions)

	<u>1999</u>	<u>2000</u>
<b>Financing Sources:</b>		
Appropriated Capital	\$2,900.7	\$2,938.3
Reimbursables	\$33.7	\$24.8
<b>Total Financing Sources</b>	<b>\$2,934.4</b>	<b>\$2,963.1</b>
<b>Shuttle Program Expenses:</b>		
Ground Processing	\$519.5	\$532.3
Flight Operations	\$230.7	\$191.9
Aircraft / Flight Crew	\$58.1	\$60.1
Reusable Solid Rocket Motor	\$382.4	\$370.1
Solid Rocket Booster	\$173.7	\$140.5
External Tank	\$366.1	\$335.6
Space Shuttle Main Engine	\$264.5	\$272.3
SSME Test Support	\$29.8	\$31.6
Vehicles	\$397.5	\$493.9
Integrated Logistics	\$192.4	\$186.9
Extravehicular Activity	\$44.4	\$43.1
Shuttle Integration	\$142.0	\$155.3
Institutional Support	\$120.3	\$137.2
Construction of Facilities	\$13.0	\$12.3



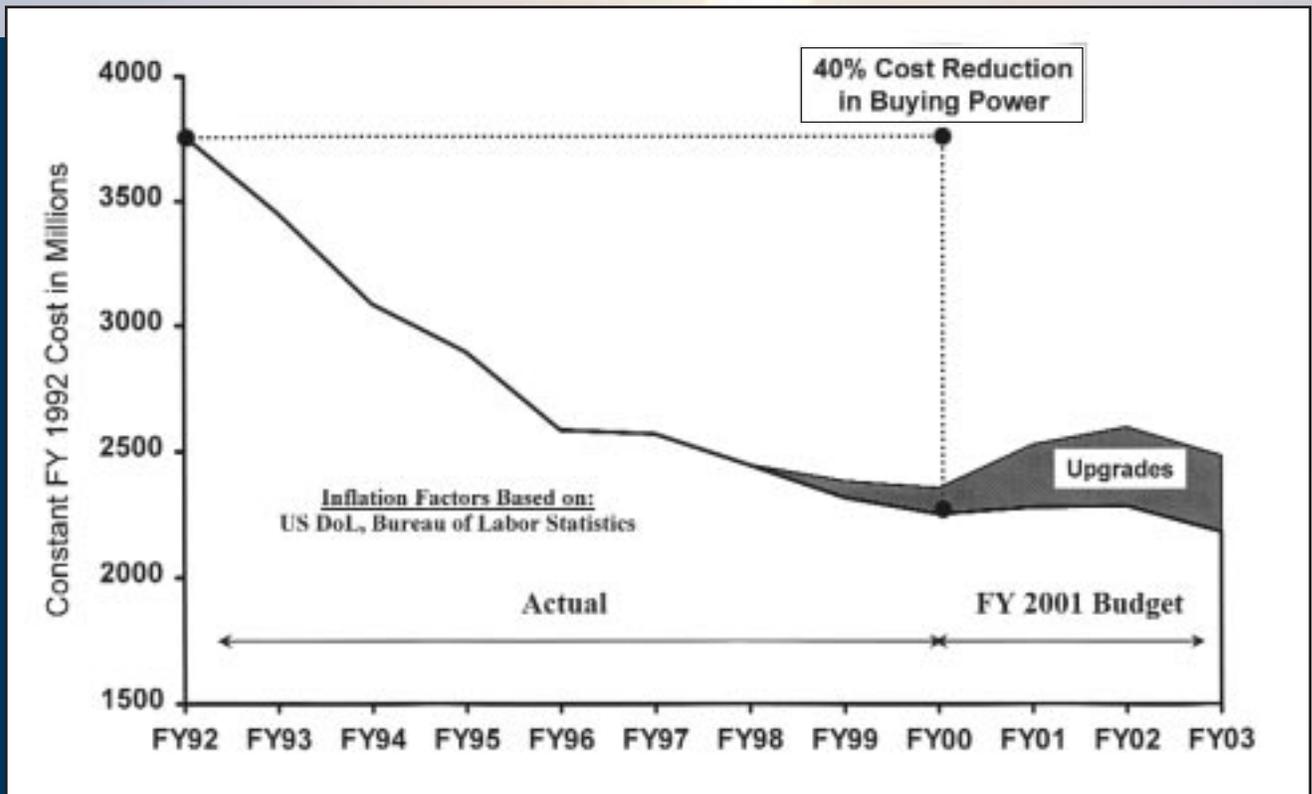
# Resource Management

While low flight rates were a contributor to the low cost expenditures for the year, our prime contractors did a great job of improving efficiency in operations that resulted in lower costs. Increases are expected in the rate of expenditures on Safety Upgrades in 2001 as the projects transition from authorization and definition to full development. Operational costs will also increase as we fly more often to build the ISS. The Program is well prepared for the higher flight rate in 2001. In addition to ISS assembly, the Program will continue to provide transportation and on-orbit human support for other science and technology customers.

The higher level of activity anticipated next year still does not saturate the Space Shuttle's capacity. The Program stands ready to add customers who are in need of the unique capabilities provided by the only reusable human space transportation system in existence today.

The following graph shows the significant cost savings the Program has achieved over the last eight years.

TOTAL BUDGET IN FY92 \$'S



# Space Shuttle Program Development (SSPD)



Eric N. McHenry  
 Manager  
 Space Shuttle  
 Development (JSC)

The most significant upgrade implemented this year by the SSPD was the new glass cockpit flown on *Atlantis* during STS-101 and STS-106. This upgrade consists of eleven new full color, flat panel display screens in the cockpit replacing 32 gauges and electro-mechanical displays and four cathode ray tube displays (see figure). The new displays are lighter and use less power than the old configuration,



GLASS COCKPIT

and provide the pilots with easier recognition of key functions. The new cockpit will be installed in all the orbiters by 2002 and will be used for a major cockpit safety upgrade planned in 2005.

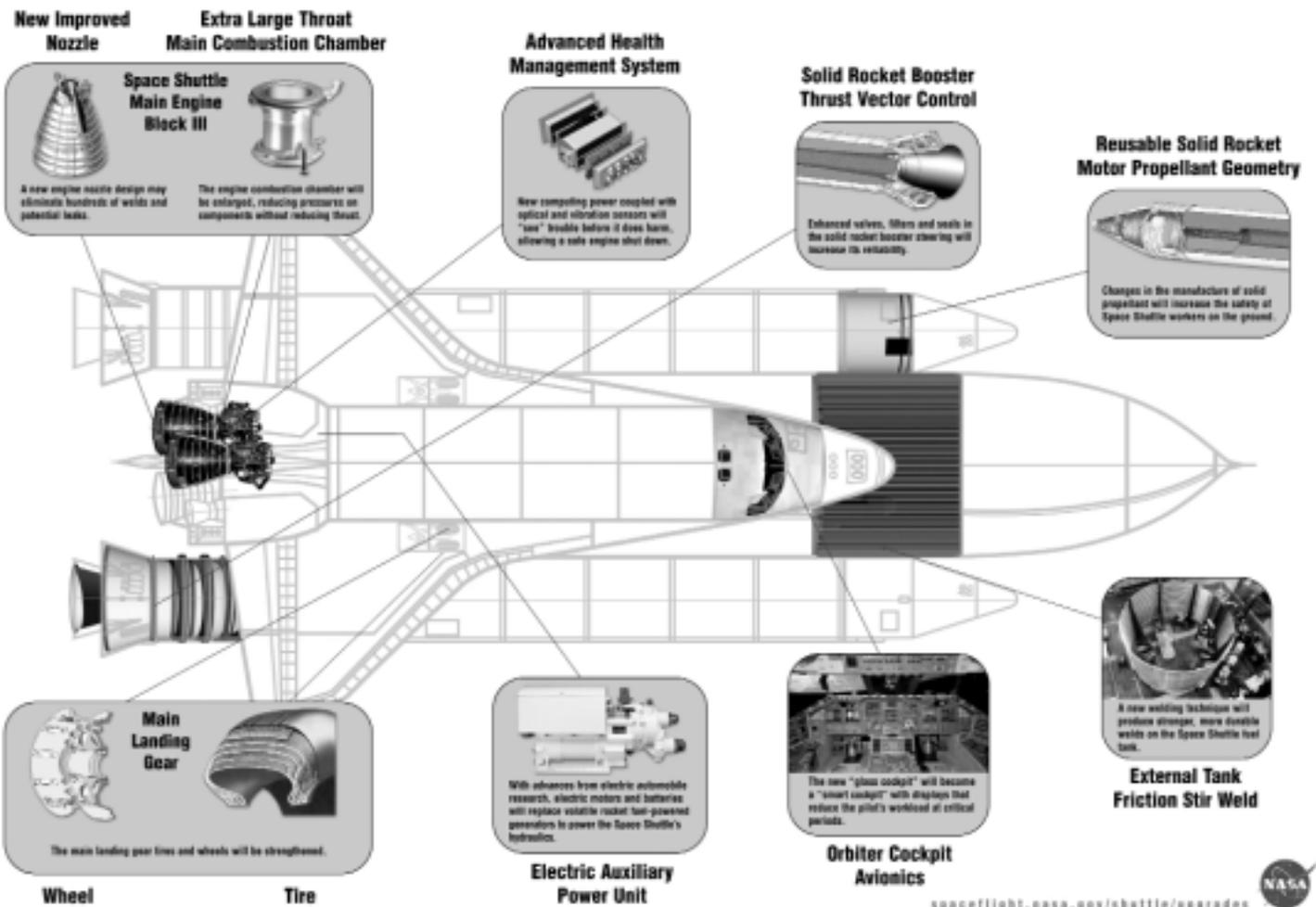
A major achievement of the SSPD has been identifying Space Shuttle upgrades that would significantly improve flight safety and reliability. The Space Shuttle elements have defined and prioritized candidate orbiter and propulsion safety upgrades. Funds for these upgrades are budgeted and the SSP has set up numerous control points that require each

phase to be examined for actual costs, schedule adherence, and potential benefit before proceeding to the next phase. Major improvements in crew and vehicle safety can be made through selected system upgrades (see figure).



# Space Shuttle Program Development

The primary upgrades under consideration are shown in the following figure and described in the following section.



SAFETY UPGRADES



# Space Shuttle Program Development

## Safety Upgrades

### **Electric Auxiliary Power Unit (EAPU)**

An EAPU is being evaluated to replace the existing hydrazine APU that drives the hydraulics to move the orbiter's main engines and aerodynamic surfaces during flight. The primary benefit will be to replace the volatile toxic hydrazine fuel and high-speed gas turbine with batteries and an electric motor. This change will significantly reduce risks associated with potential fuel leaks in flight and during ground handling.

### **Cockpit Avionics Upgrade (CAU)**

The CAU will facilitate better use of the new glass cockpit master display units. This upgrade will provide the computers, interfaces, and software that will increase the amount of information that can be displayed to the crew. These display improvements will provide added crew insight into failures, significantly reduce crew workload, increase awareness during critical flight situations, and enhance the caution and warning system for rapid problem resolution.

### **Main Landing Gear Tire**

Redesign of the orbiter's main landing gear tire and wheel will increase the tire load capacity by 20% by adding two more plies to the existing 16 and by adding new belt material. This added margin will reduce the risk of a tire failure and increase the orbiter's tolerance to cross winds while accommodating higher landing speeds. The wheel changes will compliment the tire changes and maintain or improve the current roll-on-rim capability.

### **Advanced Health Management System (AHMS)**

This upgrade provides additional health monitoring capability for the Space Shuttle Main Engine (SSME). This upgrade is planned in two phases. The first phase upgrades the SSME controller and adds a real-time turbopump vibration redline system. The second phase adds a health management computer, an optical plume anomaly detection device and a linear engine model. Each phase reduces the risk of a catastrophic engine failure by more than 20% and both increase the SSME's anomaly detection capability during ground operations and in flight.

### **Solid Rocket Booster (SRB) Auxiliary Power Unit Upgrade**

The SRB project recently completed an evaluation of several replacement options for its APU used for thrust vector control during ascent. The SRB APU, like that of the orbiter, is based on a hydrazine-powered

turbine that drives the hydraulic system pump. The goal of this upgrade is to eliminate the inherent hazards associated with the toxic hydrazine-powered system. Five options were evaluated: a pressurized helium-powered turbine that drives the hydraulic system pump, a one-pass pressurized helium/hydraulic fluid blowdown system that eliminates the pump, a similar pumpless helium/hydraulic fluid concept that recycles the hydraulic fluid, a solid propellant-fueled APU, and the EAPU. The selected option will be presented to the SSP for approval and implementation.

### **Block III SSME**

The SSME project has been studying the feasibility of an additional "block upgrade" of the main engine to further improve operational safety. The proposed upgrade involves enlarging the main combustion chamber (MCC), modifying the MCC manufacturing process to eliminate several critical welds, and completely redesigning the engine nozzle. The proposed channel wall nozzle design would provide a much more robust nozzle and, coupled with the MCC changes, would reduce the risk of catastrophic engine failure.

### **Reusable Solid Rocket Motor (RSRM) Propellant Grain Geometry Improvement**

An upgrade to modify the RSRM propellant grain geometry is being considered to improve structural margin and reduce hazardous manual inspections of the motor core. The project is currently making significant improvements in the analytical tools used to characterize the motor's structural performance. After the models have been updated, revised factors of safety will be developed to determine if the proposed grain modification is warranted.

## Supportability Upgrades

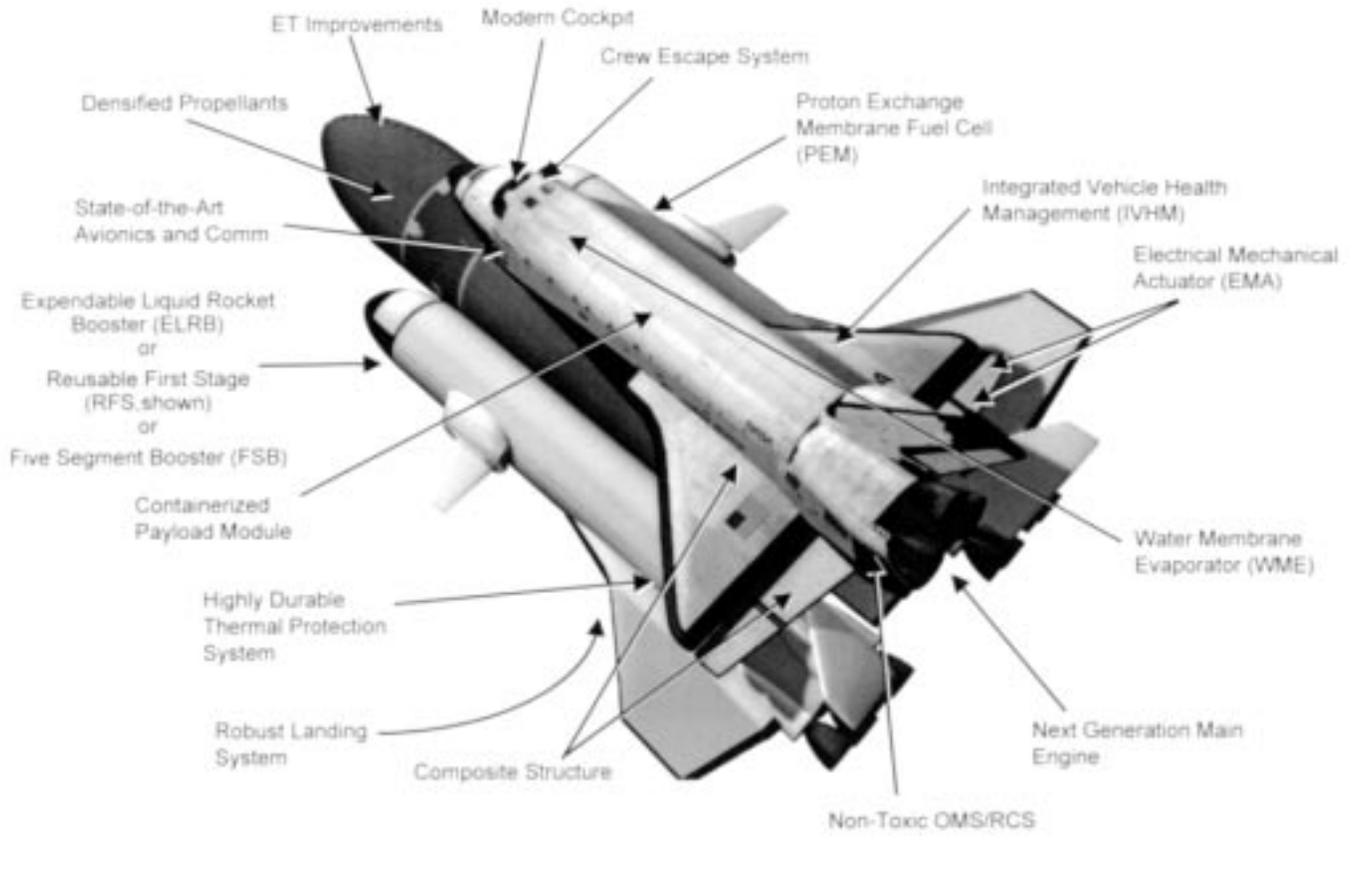
In addition to the safety upgrades, the SSPD office has been aggressively evaluating supportability improvement upgrades for the Space Shuttle. Supportability upgrade analyses address flight hardware availability assurance and operational improvements. Flight hardware availability projects consider obsolescence, failure rates, repair times, and inventory attrition. Operational improvement candidates include maintainability, mission success, flight preparation, vehicle turn-around, and cost reduction considerations. Significant supportability upgrades currently being evaluated are the orbiter's integrated communication system, the modular auxiliary data system, and certain components of the SRB's integrated electronics assembly.



# Space Shuttle Program Development (SSPD)

The Space Shuttle plays a very important role in the Agency's strategic decisions. With more than 75% of the orbiter's structural life remaining, NASA has an option to continue flying the Space Shuttle to meet commitments and goals for human access to space. It can also be used to continue support of complex payloads (e.g. the Hubble Space Telescope), as a test bed for new technology, and for human exploration and development of space. The features of an evolved shuttle concept being studied by the SSP are depicted in the following figure.

EVOLVED SPACE SHUTTLE CONSIDERATIONS



# Infrastructure Improvements

In FY 2000 the SSP Construction of Facilities budget funded the completion of the 480V electrical distribution system restoration at the Michoud Assembly Facility (MAF). This is the final phase of a 4-phase effort. The Shuttle Landing Facility (SLF) tow-way convoy operations site is under construction with the site completion scheduled for mid 2001. The Vertical Assembly Building (VAB) elevators and Pad B surfaces/slopes at Kennedy Space Center (KSC) were repaired along with Phase 1 of the A-2 Test Stand Restoration at Stennis Space Center (SSC). The A-2 Test Stand will be restored in 5 phases.

With the Space Shuttle expected to continue to fly for 15 - 20 additional years, the infrastructure supporting the manufacturing, testing, processing, and maintenance of the fleet must undergo revitalization and repair to meet the challenge. In this year's Program Operating Plan, the Program kicked off the SSP Infrastructure Revitalization Initiative in preparation for a 10- to 12- year effort to revitalize the SSP infrastructure. Although the approval for additional (augmented) funding in FY 2002 has not yet been granted, the SSP has taken initiative by approving approximately \$18M of FY 2001 funding for the initial stages of revitalization. This FY 2001 funding will provide design or studies for the MAF Chemical Clean Line System, RSRM's T-24 Static Test Stand Reactivation, and Restoration of the Test Area of RSRM Production Support Facilities.

At the White Sands Test Facility, the design for the expansion of the Oxygen Depot Test Cell, replacement of the altitude simulation system steam line, and repairs to the fabrication shop machining and quality assurance inspection equipment will be implemented.

At Johnson Space Center's (JSC) Ellington Field, the J85 Aircraft Engine Test Facility will be restored and at JSC, the EVA Thermal/Vacuum Test Chamber will be upgraded along with the SSP Electromagnetic Interference Test Facility and six degree of freedom equipment restoration. At SSC, we will begin the refurbishment of the propellant barges. Orbiter Logistics will initiate the repair and restoration of special test equipment by the original equipment manufacturers. This effort is expected to be a multiphased effort.

At KSC, the communication cabling infrastructure and the Crawler Transporter refurbishment will begin, each with multiple phases required. We will initiate the study for the VAB door mechanisms refurbishment and the replacement of the SLF approach, taxiway, and apron lighting and control. Also in 2001, the Pad B13.8KV Rotating Service Structure hinge point cable crossing will be corrected and the design and partial replacement of searchlights at the SLF and transatlantic abort landing sites will be initiated.



## Mission Summaries

### STS-103



The STS-103 mission on *Discovery* (orbiter vehicle (OV)-103) was launched on December 19, 1999, in support of the third Hubble Space Telescope (HST) servicing mission. The primary goal of the mission was to regain scientific operations by replacing failed gyroscopes. The HST had been operating in a safe mode since mid-November when its fourth gyroscope became inoperable. The HST needs at least 3 of its 6 gyroscopes operating to maintain its precise pointing capability. When the fourth gyroscope failed, the HST went into safe mode to ensure the telescope received sunlight for operation of its electrical systems, suspending all observation activity.

On the third flight day of the mission, *Discovery* rendezvoused with the telescope, captured it with the remote manipulator arm, and berthed it to a support structure allowing access for maintenance and hardware replacement. Over the following days, three space walks successfully accomplished the primary mission objectives. All 6 gyroscopes, as well as 6 voltage and temperature improvement kits and 3 remote sensor units were installed. In addition, a fine guidance sensor was replaced and a new computer was installed into the 9-year-old telescope. The astronauts also installed a new radio transmitter that the HST will use to send scientific data to the ground and replaced a reel-to-reel tape recorder with a new, improved, solid-state digital recorder.



# Mission Summaries

## STS-99



The STS-99 mission on *Endeavor* (OV-105) was initiated with a KSC liftoff on February 11, 2000, beginning the unique Shuttle Radar Topography Mission (SRTM). This advanced radar system employed a C-band and an X-band antenna at the end of a 60-meter (200-foot) mast.

The mast was deployed successfully, constituting the longest deployed structure ever to have flown in space. This was also the first time that a dual-antenna imaging radar had been flown, allowing scientists to use a technique called interferometry to map terrain elevation in a single pass. This resulted in topographic maps of Earth, between 60 degrees north latitude and 56 degrees south latitude, which are 30 times more precise than the best global maps currently in use. Joining NASA on this mission were the National Imagery and Mapping Agency, the German Aerospace Center and the Italian Space Agency, who provided the experimental X-band synthetic aperture radar system. The Jet Propulsion Laboratory managed the project for NASA's Earth Sciences Program. To keep the mast properly positioned and oriented, a series of trim burns (also called fly-cast maneuvers) were performed throughout the mission to maintain proper orbit and attitude. Seven maneuvers were performed successfully throughout the mission, with an average observed deflection of the outboard antenna of 10 inches.

At the end of 9 days and 18 hours of mapping operations, 119,500,000 square kilometers had been mapped at least once and 112,700,000 square kilometers had been mapped a second time. The cumulative targeted land imaged at least once was 99.96% of SRTM criteria and 94.6% was imaged twice. The system successfully performed 100% of the predicted data takes, after which the SRTM mast was successfully retracted and stowed at 9 days, 20 hours.

A NASA-sponsored program known as EarthKAM used an electronic still camera mounted on a bracket to the overhead starboard window of the orbiter aft flight deck and operated successfully during the mission. EarthKAM enabled middle school students to take photographs of the Earth from space. During the mission, students worked collectively and used interactive Web pages to target images and investigate the Earth from this unique perspective. A record number of images were acquired, exceeding the total number of images accumulated over the 5 previous flights.



## Mission Summaries

### STS-101

The STS-101 (ISS-2A.2a Repair/Logistics) mission on *Atlantis* (OV-104) was initiated with an on-time KSC liftoff on

May 19, 2000, and began the third U.S. mission to the ISS.

Following a successful rendezvous and docking with the ISS, one space walk was conducted to reposition the U.S. Orbital Replacement

Unit Transfer Device, transfer and assemble the Russian Strela crane, and change out the Early Communications antenna. This mission was the second flight of the Spacehab Integrated Cargo Carrier that consisted of an unpressurized cargo pallet mounted on a keel yoke assembly and was used for the mounting of external transfer items. During docked operations all preflight planned on-orbit tasks were completed as well as the transfer of 3,371 pounds of equipment and supplies between the ISS and *Atlantis*.

All of the mission objectives were met. Significant improvements to the air quality system were made and all of the ISS maintenance activities were successfully accomplished. This included restoring the Russian Functional Cargo Block (FCB) electrical system to full operation and replacing all of the FCB limited-life items providing extended functionality of the systems. The ISS was boosted to the desired altitude via the orbiter and all planned supplies and equipment were delivered to the ISS. EVAs were successfully performed, including resealing hardware and installing additional hardware. In addition to the ISS assembly operations, the crew compartment contained several payloads: Astroculture, a gene transfer experiment sponsored by the University of Wisconsin; BioTube, a precursor to a STS-107 payload, testing a newly developed seed germination method; and two crystal growth experiments sponsored by the University of Alabama. These middeck payloads met their preflight expectations and completed all planned activities.

The cargo bay contained two payloads that were used for educational purposes. Space Experiment Module 6 used a standard getaway special (GAS) canister with ten experiments from schools in the United States and Argentina. The Mission to America's Remarkable Schools GAS canister contained twenty experiments from schools in the United States. These experiments were passive and were returned to their respective schools after the flight.



# Mission Summaries



## STS-106



The STS-106 (ISS-2A.2b Repair/Logistics) mission on *Atlantis* (OV-104) was initiated with an on-time KSC liftoff on September 8, 2000, and began the fourth U.S mission to the ISS.

Because of the energy gains realized from the on-time lift off, successful flight-day 3 rendezvous and docking and conservation steps taken during the first four days of the mission, the flight duration was extended from 11 to 12 days. All of the planned mission objectives were completed successfully, including 22 tasks that were added and completed during the flight. Two Service Module batteries were installed and two FGB batteries were removed and replaced. The crew quarters were prepared for the arrival of the first ISS residents.

This mission was the third flight of the SPACEHAB Logistics Double Module and the Integrated Cargo Carrier, used for the mounting of external transfer items.

During docked operations all preflight planned on-orbit task priorities were completed, including over 5,399 pounds of EVA and intravehicular activity transfers from the Space Shuttle to the ISS and approximately 3,000 pounds of hardware from Progress to the ISS. The ISS vehicle was raised approximately 12.3 nautical miles (nmi) to the desired altitude via four orbiter reboost maneuvers, which preserved ISS propellants in preparation for the STS-92/ISS-3A launch. The ISS was left in a 208 x 204 nmi orbit and should be at 206 x 203 nmi orbit for the STS-92/ISS-3A mission.

Located in the middeck, the Commercial Generic Bioprocessing Apparatus (CGBA) was a cooperative commercial experiment facility sponsored by the Space Product Development Program at the Marshall Space Flight Center (MSFC). The CGBA allowed automated in-flight processing of a variety of biological experiments contained in eight individual programmable, temperature-controlled devices.

GAS-782 and Space Experiment Module (SEM) canisters were located in the payload bay. Three hundred students from eight St. Louis, Missouri, schools in cooperation with Washington University designed and prepared experiments that were flown as part of GAS-782. Thirteen experiments were flown as part of the SEM payload. These experiments were created and built by students from all over the United States. Goddard Space Flight Center sponsored both of the programs. GAS-782 and SEM were passive payloads and the experiments were returned to their respective schools after the flight.



## STS-92

The STS-92 (ISS-3A Assembly) mission on *Discovery* (OV-103), with six American astronauts and one Japanese astronaut on board, was initiated on October 11, 2000, and began the fifth U.S. mission to the ISS. The primary mission objective was to launch, rendezvous and dock with the orbiting ISS and deliver the 3A launch package. The Z1 Integrated Truss Segment was attached to the Node 1 zenith port and the Pressurized Mating Adapter 3 (PMA3), which was launched on a Space Logistics Pallet (SLP), was mated to the Node 1 nadir port. Two direct current (DC)-to-DC converter units were installed on Z1 and checked out successfully. The Z1 and PMA3 power and data umbilical wire harnesses were reconfigured in preparation to support STS-97/4A docking to PMA3. Additionally, two EVA tool stowage devices were relocated from the SLP to Z1.

The IMAX 3D cargo bay camera successfully documented scenes of the Space Shuttle approach, ISS assembly tasks, EVA crew activities, and undocking. All planned and get ahead tasks were completed with four EVAs in a total time of 26 hours and 38 minutes.

The ISS vehicle was raised approximately 3.6 nmi to the desired altitude with three Shuttle reboost maneuvers that preserved ISS propellants in preparation for the STS-97/4A launch. The ISS vehicle was left in a 214 x 202 nmi orbit.



# MSFC External Tank



Jerry W. Smelser  
External Tank (MSFC)

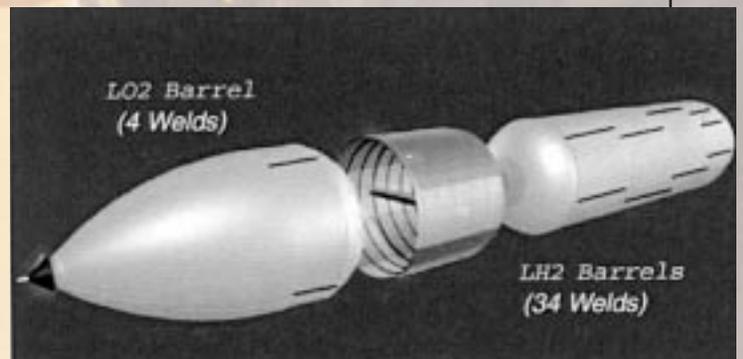
## External Tank (ET) Friction Stir Weld (FSW) Safety Upgrade

FSW technology is being implemented as a Space Shuttle upgrade on the ET program for longitudinal welds. This new material joining process will improve the margin of safety for welds, reduce cost, and mitigate schedule challenges presented by fusion arc welding of 2195 aluminum lithium on the Super Lightweight External Tank (SLWT). This technology replaces the existing fusion arc weld process and its associated weld repairs with a solid-state process, which provides superior welds, is less labor intensive, less technically complex and easier to control.

Initial fusion welds on the liquid hydrogen (LH2) and liquid oxygen (LO2) barrels are being replaced with FSW. FSW is a solid-state welding process that produces welds with higher strength and ductility than fusion arc welding. The FSW technique provides

the best possible initial weld for 2195 aluminum lithium on ET barrels, produces almost defect-free welds, and reduces manufacturing cycle time.

The ET barrels are 8 feet to 20 feet in length and 27.6 feet in diameter. In order to develop the FSW process for such massive hardware, MSFC successfully built a full-scale demonstration article using non-production ET hardware. The FSW technique will be applied to approximately 8,000 inches of ET welds.



FRICITION STIR WELDS INDICATED WITH BLACK LINES



# MSFC External Tank

The FSW process for barrels will be fully implemented in the second quarter of FY 2002. Two new universal FSW tools, capable of welding all ET barrel configurations, will be installed and activated to weld barrels in the vertical position. When these tools are in production, there will be immediate improvement in safety, reliability, and cost for the ET program.



FRICION STIR WELD TOOL (MSFC DEMO)

The latest MAF Toxic Release Inventory Report documented pollution prevention accomplishments that have achieved an 88% reduction in toxic chemical releases compared to the 1987 Environmental Protection Agency baseline. Pollution prevention program improvements have virtually eliminated the use of certain toxic chemicals and emissions of Class I ozone-depleting compounds.

The MAF environmental program has also worked aggressively to avoid ET project costs. In 2000, MAF negotiated with the Louisiana Department of Environmental Quality a "No Further Action" alternative for eight areas of soil and groundwater contamination at MAF avoiding an estimated \$12M in future site remediation costs.



FRICION STIR WELD TOOL

## Michoud Assembly Facility (MAF) Environmental Management Program

In FY 2000, MAF demonstrated sustained outstanding environmental compliance and operations. Performance was documented by unannounced regulatory agency inspections of MAF Clean Air Act and Hazardous Waste Management program compliance, and MAF Oil Pollution Act and Clean Water Act spill response plans and capabilities. No compliance violations or enforcement issues were noted during the inspections.



INDUSTRIAL WASTEWATER TREATMENT FACILITY



# MSFC Reusable Solid Rocket Motor



Michael U. Rudolphi  
Reusable Solid Rocket  
Motor (MSFC)

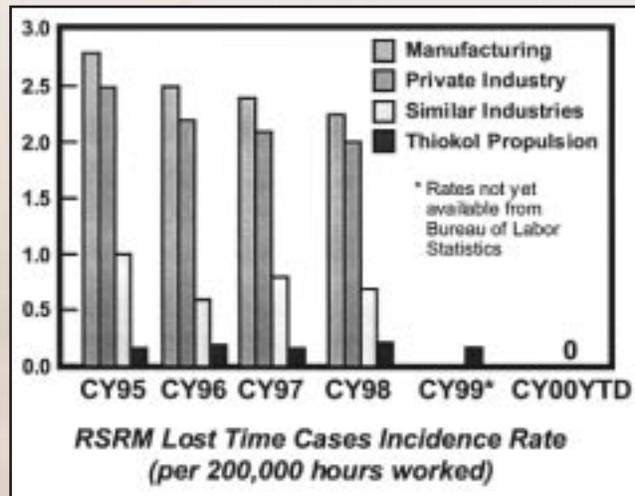
## Reusable Solid Rocket Motor Project Performance Highlights

On March 14, 2000, Alcoa Inc., announced the acquisition of Cordant Technologies Inc., parent company of Thiokol Propulsion. With the merger, Thiokol and the other two units of Cordant Technologies (Huck and Howmet)

have been included in Alcoa's new Salt Lake City-based Industrial Components Group.

RSRM thrust performance was right on the predicted target for each of the Space Shuttle launches this year. No significant anomalies were identified either during ascent or during subsequent postflight disassembly and inspection of the recovered motors. All RSRM segments for FY 2000 were delivered on schedule, making this the tenth consecutive year of on-schedule RSRM deliveries to KSC.

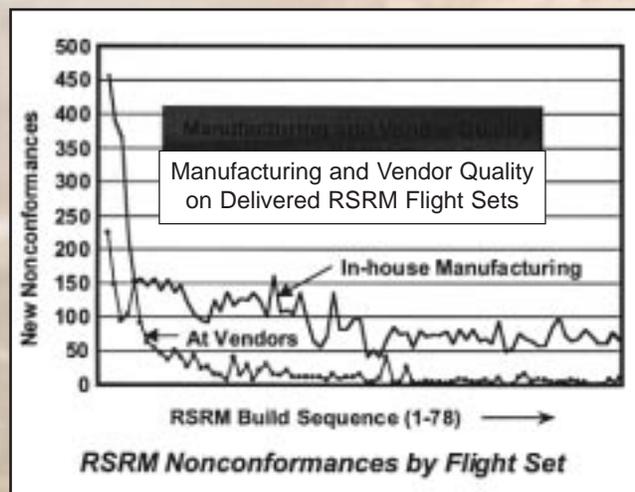
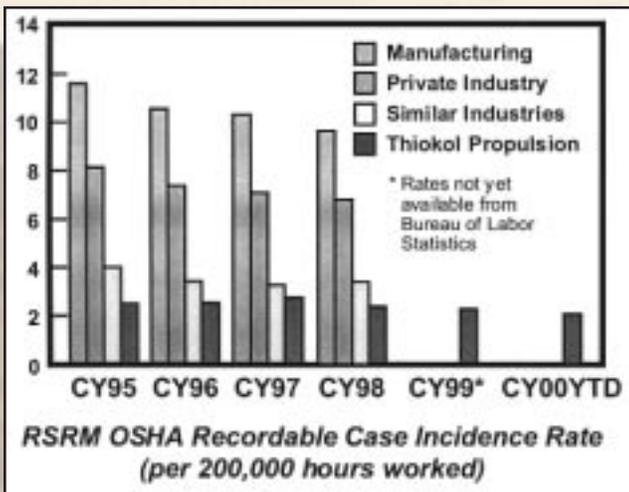
Safety continues to be the principal focus in the manufacture of the RSRM and is reflected in the job-related accident frequency rates at Thiokol Propulsion, which have been well below the rates for similar industries, as published by the Bureau of Labor Statistics. Because of low accident rates, Thiokol Propulsion qualified for the National Safety Council's Perfect Record Award for operating over 5 million hours without an occupational injury or illness involving days away from work (from September 1999 to present). In addition, National Safety Council Safe Driver Awards were presented to assigned company vehicle operators with no accidents during 1999. Of the drivers awarded 22% had over 20 years without a vehicle accident on the job.



The RSRM program continued to focus on employee safety awareness, conducting several safety initiatives throughout the year that included:

- "Focus on Safety Day" and "Safety Start-up Day," when special safety inspections and meetings were conducted by employees throughout the plant
- "Safety Month," which included special safety activities (e.g., several energetic material demonstrations, a special safety luncheon, and a unique Occupational Safety and Health Administration regulations training class)
- Lockout/Tagout Training Manual update, machine guarding improvements, pressure vessel interlock improvements, and a live area safety review

The RSRM program has progressively improved productivity and quality over the last decade. Quality conformance for each motor exceeds 99.996% with RSRM manufacturing nonconformances leveling off at a low rate.



# MSFC Reusable Solid Rocket Motor

## RSRM Test Accomplishments

### Full-Scale RSRM Test Motors

Full-scale RSRM static test motors are periodically tested to confirm the performance and safety of RSRM systems, components, materials, and processes. Flight Support Motor (FSM) and the newly approved Engineering Test Motor (ETM) programs also provide the opportunity to evaluate, demonstrate and certify many design, process and material changes. FSM-8 was successfully static tested February 17, 2000. All test objectives were met. The next FSM test firing (FSM-9) is scheduled for April 2001. The manufacturing of FSM-9 commenced this fiscal year and includes the following significant test objectives:

- Additional performance data of new nozzle structural adhesive
  - Performance data from new nozzle-to-case joint J-leg design
  - Performance data on components cleaned with ozone-depleting-chemical (ODC) free cleaners
  - Aft exit cone performance data of multiple rayon candidates being considered as replacements for the discontinued North American Rayon Company (NARC) product
- A full-scale ETM (ETM-2) is scheduled to be test

### MNASA Motor

During FY 2000, two MNASA motors were successfully tested. These large test motors provide a ballistic environment similar to the full-scale RSRM with test components that are approximately one-fifth scale.



MNASA-12' FIRING AT THIOKOL

### 24-inch Solid Rocket Test Motor (SRTM)

The RSRM program has developed a new 24-inch-diameter one-segment SRTM (as shown) primarily for testing RSRM nozzle components. A successful 24-inch SRTM preliminary design review (PDR) was conducted June 23, 2000, with the critical design review (CDR) scheduled for

the first quarter of FY 2001.

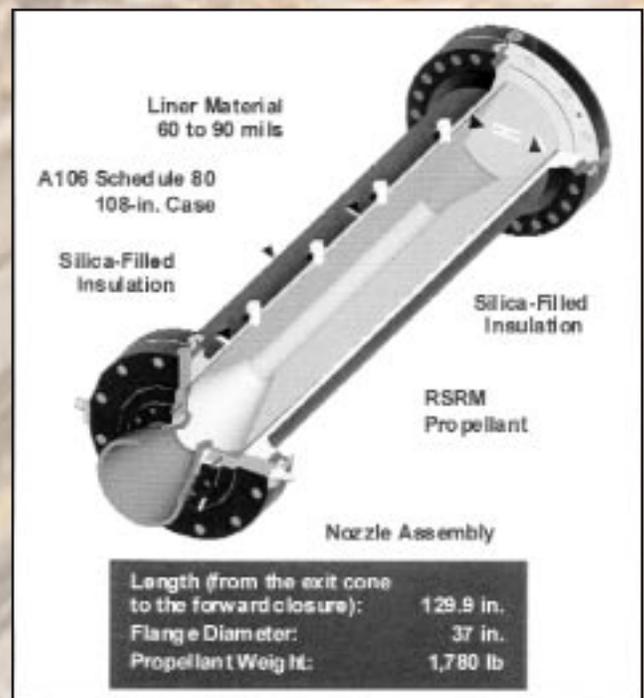
The 24-inch SRTMs will fill an important gap between the large MNASA test motor and smaller subscale test motors. They will provide a relatively low-cost, fast turn-around representation of the RSRM internal environment.



RSRM FLIGHT SUPPORT MOTOR FIRING

fired September 2001. The manufacturing of ETM-2 commenced this fiscal year with many significant test objectives to measure:

- Performance of NARC rayon replacement candidates
- Nozzle joints 1, 2, and 5 performance data
- Performance data on stand-alone (intelligent) pressure transducers



24-INCH SOLID ROCKET TEST MOTOR



# MSFC Reusable Solid Rocket Motor



NJES-4B STATIC TEST

## Nozzle Joint Environment Simulator No. 4 (NJES-4)

This year, two NJES motors were tested. These motors evaluated the new nozzle-to-case J-leg insulation design with and without a joint flaw. The propellant configuration was designed to provide a normal internal pressure rise and peak pressure similar to flight motors in a closed bomb test.

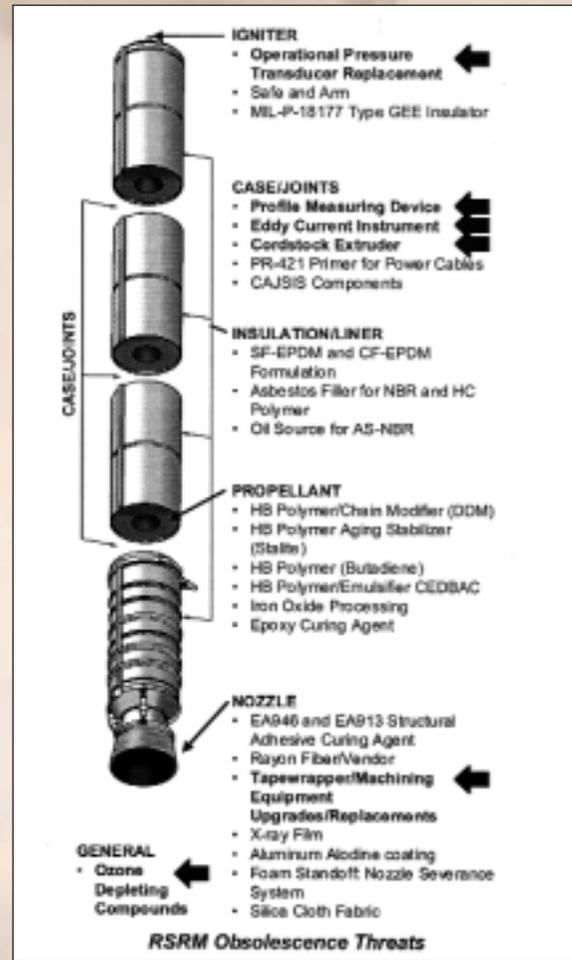
## RSRM Obsolescence Mitigation

The uninterrupted supply of unchanged components and materials is often challenged by factors such as state and federal regulation changes (including environmental, health, and safety), continued supplier and sub-tier supplier availability, supplier and sub-tier supplier process enhancements, equipment and facilities aging and replacement. The arrows in the following figure depict the current obsolescence threats that the project is working.

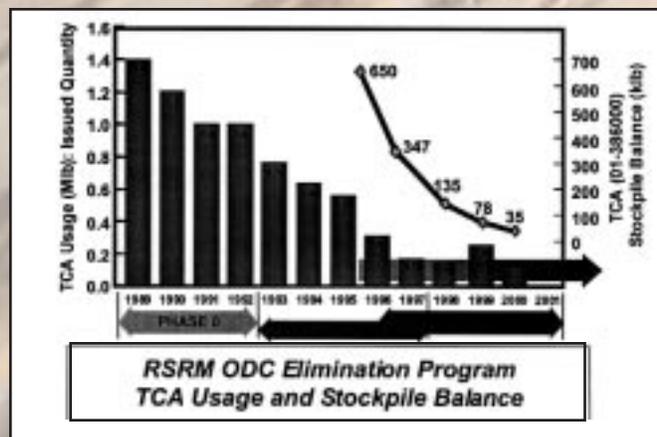
## Ozone-Depleting Chemical Elimination

Methyl chloroform (TCA) production has been banned for emissive uses such as those employed to manufacture the RSRM. Aggressive testing and investment in leading-edge technology has enabled the RSRM program to redirect the manufacturing process and reduce the use of TCA by over 1.1 million pounds per year.

The RSRM program is in the final phase of its ODC elimination program. The current effort is dedicated to eliminating the remaining 10% of TCA



usage involved in the hand cleaning of bonding and assembly surfaces, as well as rubber activation. Extensive FY 2000 laboratory testing led to the down selection of three cleaner candidates in August 2000 that perform equal to or better than TCA in cleaning performance and bond properties. Full-scale process simulation articles have been initiated that will lead to the selection of a cleaner for a full-scale static test on FSM-9.



# MSFC Reusable Solid Rocket Motor

## Nozzle Rayon Replacement

The RSRM program is developing a replacement for rayon yarn, a precursor material in the manufacture of carbon cloth phenolic (CCP) ablatives for the RSRM nozzle. The previous rayon yarn supplier, NARC, discontinued production in September 1997. Before the shutdown, the RSRM program procured a stockpile that will support RSRM production through 2005.

Four candidate materials have been down-selected for the Phase II and III test matrix. Four candidates were also tested on MNASA-11 and a single candidate tested on MNASA-12. All five demonstrated ablative characteristics comparable to the current rayon-based CCP. Ultimately, the best fiber candidate will be selected in early 2002 and tested in three full-scale static test motors before use in a production RSRM nozzle. The first production nozzle made with the selected replacement fiber is targeted for the spring of 2005.

## Operational Pressure Transducer (OPT)

The RSRM program is in the process of completing the qualification of a new flight OPT supplied by Stellar Technologies. Qualification testing will include full-scale RSRM demonstration, electromagnetic compatibility, vibration, calibration, dynamic response, and various other tests to ensure the new OPT will be a complete drop-in replacement for the obsolete unit. A Design Certification Review is scheduled for the fall of 2000. OPTs are refurbished and reused for multiple RSRM flights.

## RSRM Critical Skills Knowledge Enhancement/Technical Initiatives

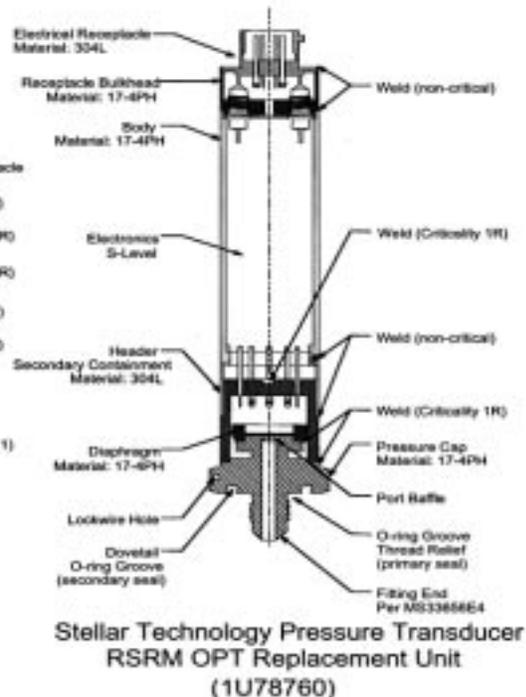
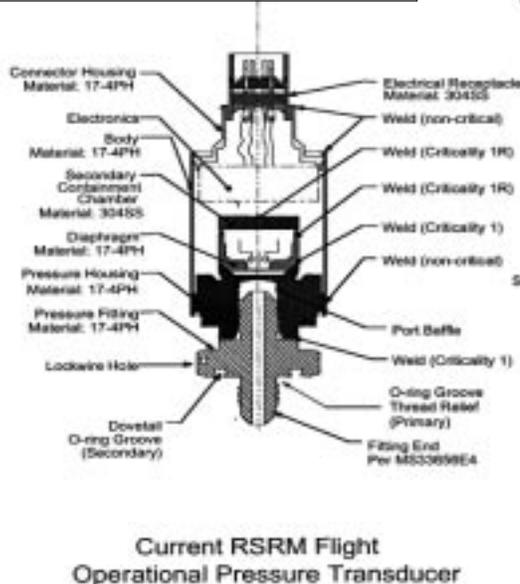
In pursuit of safely flying the RSRM and the Space Shuttle for the next decade, the most significant enhancement from an RSRM perspective is developing improved material and process controls, improved design margins, enhanced inspection capability, improved margin assessment capability, and maintaining critical skills.

The initiatives discussed below have delivered tangible safety and reliability benefits to the current flight program while providing engineers and scientists with improved tools and capability to prevent, assess and mitigate program issues. These initiatives provide challenging, important work for talented individuals that allow the RSRM program to attract and retain new talent. In addition, the programs provide excellent skill development opportunities such as technical leadership, project leadership, and communication. Lastly, these programs ensure that talented technical people with the necessary skills and experience are available in a crisis, which is critical to continued RSRM mission success.

## RSRM Enhanced Sustaining Engineering (ESE) Project

The ESE project is a 5-year plan designed to enhance RSRM safety and reliability by advancing knowledge about the RSRM's design, performance, materials and processes. It is a comprehensive solid

REPLACEMENT RSRM OPERATIONAL PRESSURE TRANSDUCER



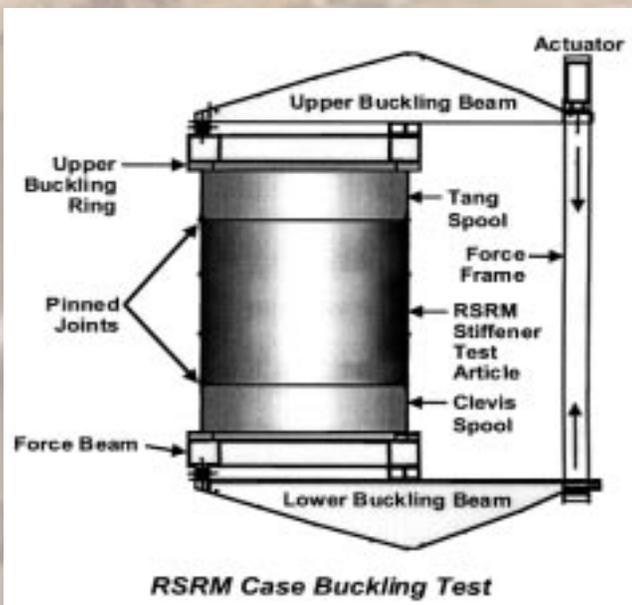
# MSFC Reusable Solid Rocket Motor

rocket motor technology program of 11 tasks (9 main tasks, 2 subtasks) directed specifically at the RSRM as identified below:

- Analytical models and material properties upgrades
- Chemical fingerprinting for RSRM critical materials
- Process validation and sensitivity studies
- Nozzle internal joint improved thermal barrier system
- Nozzle structural test bed
- Statistical process control/trending at key suppliers
- Digital X-ray inspection
- Metal component nondestructive evaluation enhancement
- MNASA motor testing
- Propellant-to-liner-to-insulation bond line integrity

## RSRM Case Buckling Capability

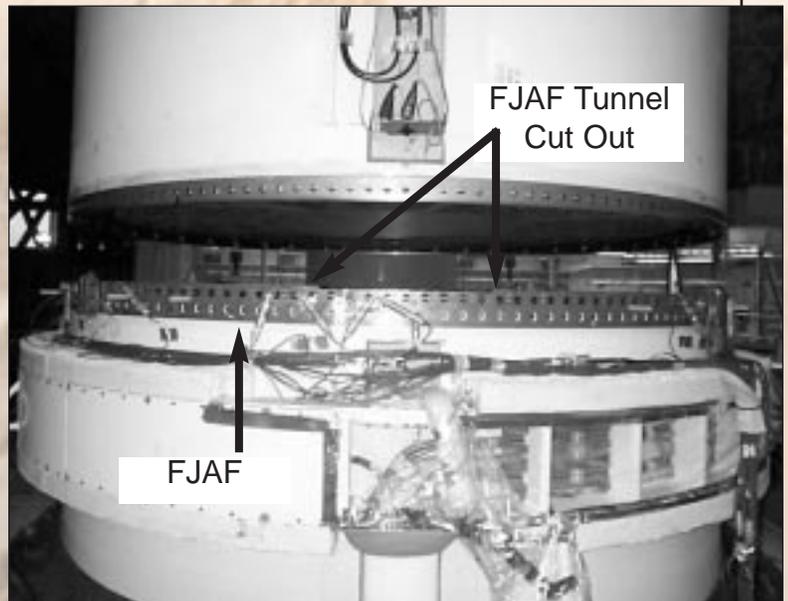
Each Space Shuttle launch is subjected to hundreds of constraints designed to ensure flight safety. Wind speed is one constraint critical to the RSRM, as it affects the structural loads on the RSRM cases. The RSRM case supports the entire vehicle on the launch pad. As the orbiter's main engines start, the Space Shuttle bends over approximately 3 feet at the top of the external tank. Wind loading can add to this bending, especially southerly winds. The RSRM cases must resist this bending before the stack springs back to vertical and the RSRMs are ignited. In FY 2000, the non-linear analytical methods



developed during the test program were used to create a full-scale finite element model, including the RSRM, mobile launch platform, and aft skirt assembly. The new analysis, validated by full-scale test data, was approved for use on STS-106, thereby increasing RSRM certification from 15 to 24 knots for southerly winds.

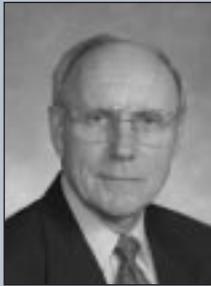
## Field Joint Enhancement Test

Field joint mating of RSRM segments is a complex interaction between the lifting beam loads, propellant relaxation rate, segment shape memory, engagement rate and Field Joint Assembly Fixture (FJAF) stiffness. A successful field joint mate requires all of these factors to be controlled so that the two segments can be mated without damage to metal surfaces or O-rings. In an effort to reduce assembly times, it was proposed that the FJAF provide more shaping and rely less on the time-consuming process of multiple changes to the lifting beam loads to change the segment shape before mating. The certification testing has been completed with Program approval and implementation expected in 2001.



RSRM-76A AFT FIELD JOINT SHAPING TEST SETUP





Parker V. Counts  
Solid Rocket Booster  
(MSFC)

## Solid Rocket Booster (SRB) Thrust Vector Control (TVC) Upgrade

The SRB TVC system was identified at the beginning of FY 1999 as a potential area to improve Space Shuttle ascent flight safety. The SRB TVC accounts for approximately 35% of the risk associated with the Space Shuttle's mission based on the use of monopropellant hydrazine as the APU fuel source. To mitigate these risks, the SRB Project initiated efforts to develop an advanced TVC system having increased reliability and reduced operational risks.

The SRB Project, located at MSFC, has design responsibility for the TVC upgrade with support from the prime contractor, USA. The primary objective of the SRB advanced TVC upgrade is to measurably improve the flight safety and reliability of the SRB. Secondary objectives are to improve ground safety by eliminating the use and processing of hydrazine, a highly toxic substance, and provide cost-effective supportability through the life of the Space Shuttle Program. The SRB TVC upgrade will be transparent to the Space Shuttle flight control systems and will minimize impacts to interfacing systems of the orbiter.

The initial phase of the SRB TVC upgrade consisted of conducting technology demonstration and trade studies of five selected candidates. The candidate technologies developed for this activity were a pressurized helium-powered turbine that drives the hydraulic system pump, a one pass pressurized helium/hydraulic fluid blowdown system that eliminates the pump, a similar pumpless helium/hydraulic fluid concept that recycles the hydraulic fluid, a solid propellant-fueled APU, and an electric APU. Demonstrations of the five concepts were successfully completed and final reports were delivered for evaluation at the end of July 2000. All concepts were able to meet the SRB requirements. The final portion of the feasibility and formulation phase will be complete by the third quarter of FY 2001.



# MSFC Space Shuttle Main Engine



George D. Hopson  
Space Shuttle Main  
Engine (MSFC)

## Space Shuttle Main Engine High-Pressure Fuel Turbopump/ Alternate Turbopump (HPFTP/AT) Certification and Flight Status

Pratt & Whitney's HPFTP/AT completed certification in May 2000 on the Block II SSME with

two units that tested 22 ground hotfires each. The testing was done at NASA's SSC in Mississippi starting in October 1999 with unit F12-1 and completed May 2000 with unit F13-1. A design certification review was completed in September 2000, verifying that the new configuration is certified and flight worthy. Currently, the manifest has the first Block II SSME scheduled to fly on STS-100 in April 2001.

The HPFTP/AT had past design challenges that were overcome through redesigns to the hardware. Development and certification testing verified the resolution of these design challenges and provided confidence in the robustness of the turbopump. The development and certification program accumulated more than 111,000 seconds of total ground test time. Adding this turbopump to the fleet will add safety to the SSME, reduce ascent risk for the Space Shuttle, and reduce the requirement for between flight maintenance.

## Advanced Health Management System (AHMS) Development Status

The AHMS is a high-priority SSME safety upgrade which, when implemented, will reduce SSME catastrophic ascent risk by approximately 40%. This risk reduction will be achieved through the application of improved sensing technology on the high-pressure turbomachinery and nozzle combined with advanced health management algorithms, engine modeling, and real-time processing technology. AHMS is to be implemented in two phases – Phase 1, which focuses on the design, development, and implementation of upgrades to the existing SSME controller shown in the figure, and Phase 2, which provides for the design,



CURRENT SSME CONTROLLER

development, and implementation of a new Health Management Computer (HMC).

Phase 1 of the AHMS Project was given authorization by the Space Shuttle Program Requirements Control Board (PRCB) in October 1999. An intensive requirements definition activity culminated in a formal system requirements review (SRR) that was successfully conducted in November 1999. Phase 1 design concepts were then developed by the controller supplier, Honeywell, Inc., and presented at the PDR conducted in April 2000. The AHMS project team is working toward the definition and release of the controller detailed design, which is to be formally reviewed during the Phase 1 CDR, scheduled for February 2001.

Initial Phase 2 prototyping and requirements definition tasks (Phase 2A) of the AHMS Project were given formulation authorization by the PRCB in January 2000. An incremental SRR for the protoflight HMC was conducted in March 2000. An SRR for the Optical Plume Anomaly Detection (OPAD) flight experiment was successfully conducted in July 2000. The next milestone reviews for both the HMC and OPAD flight experiment are planned in November 2000 with a Program decision point on the final Phase 2 HMC flight system scheduled for March 2001.





Gregory J. Harbaugh  
Manager, EVA Projects  
Office (JSC)

## Extravehicular Activity STS-103 (3A) Lessons Learned

As a result of the three long EVAs performed on STS-103 (3A), a review of the EVA planning process and EVA duration constraints was initiated. The reviewers implemented a policy that the end-to-end EVA planning duration will be limited to 6-1/2 hours. This decision took into account such factors as impacts to the standard crew day, EVA crewmember physiological factors and Extravehicular Mobility Unit (EMU) specifications. Based upon a review of historical Neutral Buoyancy Laboratory (NBL) training durations and actual EVA time, a correction factor of 20% will be applied to all NBL training at the mid-point flow. This 20% correction factor accounts for the differences between the training in the NBL water environment and the actual in-flight EVA operations. This new policy and process was successfully implemented on STS-101 (2A.2a).

## Pursuit of EMU Contamination Root Cause and Corrective Action

In June, 2000 NASA was informed that contamination was found within the EMU Secondary Oxygen Package (SOP) regulators. The contamination was a combination of fluorocarbon and hydrocarbon non-volatile residues. Composition and amount of contamination varied from unit to unit. In all flight units examined (12 total), the amount of contamination was far in excess of allowable limits for safe operation in a high-pressure oxygen system. The most likely cause was accumulation of contamination from trace amounts in the oxygen and nitrogen gas supplies over the 10-year operation of these regulators. Remedial corrective action included disassembling and cleaning all flight SOPs and adding cold trap filters and sampling equipment to the test rigs to ensure contamination does not reoccur.



STS-101 EVA



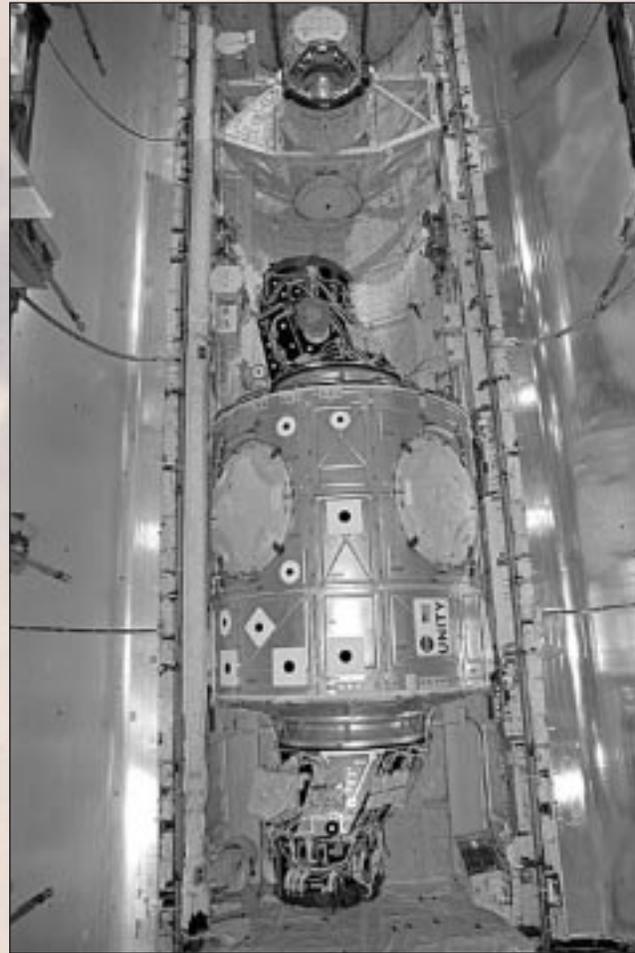
# JSC Systems Integration Office



Lambert D. Austin  
Manager, Systems  
Integration (JSC)

## Orbiter - Payload Integration Standardization for International Space Station Assembly Missions

Standardization of orbiter-payload interfaces and services from the aft flight deck into the payload bay for ISS assembly flights is a SSP initiative approved in July 1999 to efficiently accommodate ISS schedule dynamics. Standardization provides the SSP flexibility to move entire ISS assembly payload complements and integration hardware from one orbiter to another after release of the mission's reconfiguration engineering with little or no impact to orbiter ground processing. As a result, programmatic decisions to swap vehicles as late as 4-1/2 months before launch may be implemented without impeding ground operations, crew training, flight software development or flight operations. Incorporation of the standardized aft flight deck services will be implemented on STS-102 (ISS mission 5A.1).



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Manager, Customer and  
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## Improved Customer Processes

The SSP and ISS are jointly evaluating the processes that a customer experiences when flying a payload within both programs. The goal is to consolidate and simplify common processes to minimize the burden on the customer when their payload is manifested on both platforms. Several customers have been invited to share their experiences of processing a payload for flight in each system. Based on their recommendations and also on areas identified by team members, focus teams have been formed. These focus teams, consisting of members from multiple Centers as well as from

# JSC Customer and Flight Integration

each program, are identifying specific issues and potential recommendations as appropriate. Depending on the team, the recommendations are anticipated to address documentation, data formats, and templates. Focus teams have been organized to review:

- Manifest processes for Space Shuttle middeck payloads
- Common requirements for middeck/subbrack payloads
- Customer integration processes for SSP and ISS payloads
- Tools provided by the SSP and ISS for use by the customer
- Procedure formats and onboard displays



# JSC Space Shuttle Vehicle Engineering Office



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## Space Shuttle Vehicle Engineering Office (SSVEO) Avionics and Software

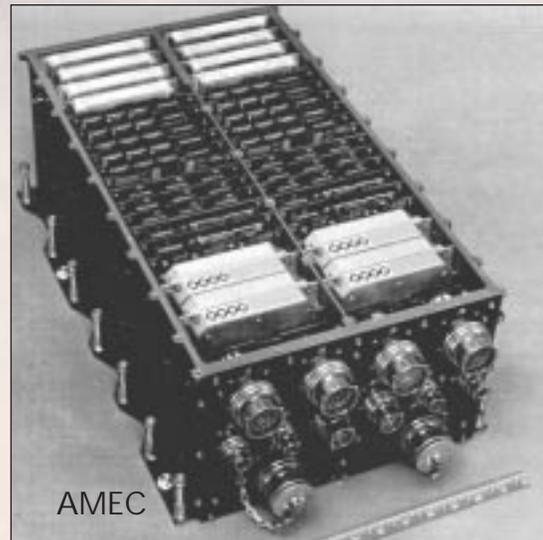
Software upgrades during the last year have supported numerous SSP requirements, upgrades, and operational improvements. Some of the highlights include support to three-string global positioning satellite capability that will relieve the Space Shuttle's dependency on the tactical air command and navigation system and just-in-time flight design support to accommodate late mission requirement changes. Plans for the next software increment will support Multipurpose Logistics Modules to be used extensively on ISS flights and expanded functionality of the Multifunction Electronic Display



System (MEDS) that was flown for the first time this year on STS-101 (see photo).

An advanced air data transducer assembly (ADTA) replaced the old units beginning with STS-106. These quadruple-redundant sensors provide air speed and altitude data for use by the onboard guidance and navigation systems during entry and landing. The ADTA increases pressure measurement stability through the use of digital circuitry, eliminates costly periodic calibration and requires no active cooling.

The redesigned Advanced Master Events Controller (AMEC) also had its first flight on STS-106. The AMEC, as shown in the picture, replaces the Master Events Controller (MEC) and provides the transfer and signal conditioning of control and measurement data between the general purpose computers, the orbiter, ET, and SRB pyrotechnic and control devices. The AMEC controls SRB power switching, SRB ignition, and ET separation. On STS-106, a MEC was flown in one position with the AMEC in the other position to verify the new controller's flight performance. The AMEC eliminates



criticality 1R2 failure modes and solves electronics parts obsolescence problems, high failure rates, and high repair turnaround times associated with the MEC. The full upgrade will be completed on STS-98 in January 2001 with the flight of two AMECs.

## Orbiter Major Modifications (OMMs)

### OV-102 Modifications

Columbia (OV-102) is undergoing its third OMM cycle at Boeing's Palmdale, California, facility. The orbiter arrived on September 26, 1999, for an initial ten-month stay for structural inspections and modifications. Significant upgrades have included incorporation of the MEDS, orbiter docking system scar for future ISS mission support, radiator Freon loop protection and automatic isolation capability, body flap refurbishment, removal of development flight instrumentation wiring, and a multitude of safety and operational enhancements. Approximately 1,000 pounds of unused wiring has been removed, enhancing Columbia's weight to orbit capability. Structural inspections concluded that the overall structure has no significant defects.



# JSC Space Shuttle Vehicle Engineering Office

However, several areas were experiencing active corrosion which required passivation and application of corrosion protective compounds to alleviate future concerns.

## **Orbiter Wiring Modification**

The Program continues to make significant progress on wiring-related actions and improvements. After a short circuit occurred in a midbody wire tray during the launch of STS-93 in July 1999, all orbiters were inspected and wiring was repaired where damage was found. Protection has been added to wire harnesses throughout the orbiter fleet to reduce the potential for work-induced damage. The wire inspection specification was clarified and wire inspection requirements were updated. KSC has developed a new wire awareness and protection training video that is now required viewing for everyone with orbiter access. KSC has also developed a wire inspection certification-training course and is currently training inspectors.

The Program continues to pursue orbiter design changes that will enhance wire protection and safety. Convoluted tubing is being added to the aft sidewall of each vehicle and temporary protection methods are also being implemented. Design changes have been made to orbiter access platforms at KSC and Palmdale that increase their "wire friendliness." The Program made a design change to the landing gear down circuit that will eliminate a potential single wire catastrophic failure mode, and modifications to other critical circuits are being investigated. Orbiter design changes have been proposed for 127 areas where all the redundancies for a critical function are routed together. Implementation of these routing changes will be made during OMMs or during orbiter flows at KSC. The Program is also modifying the wiring harness that connects the orbiter to the ET, called the monoball, to improve technician access and handling during turnaround. This will make wire damage in this susceptible area less likely. Another ongoing study is looking at redesigning the midbody wire tray covers to provide more room for wire bundles in the trays and to eliminate possible scuffing of the wire bundles by the tray cover nut plates.

Several test programs are under way to characterize the performance of the orbiter wiring under various conditions. Old, flown wire is being compared to new wire to establish an aging baseline. Another series of tests will compare the potential of old and new wire to sustain arc tracking.

Results will be compared to testing done at JSC in 1990 and corrective action will be applied if deemed necessary.



TYPICAL WIRING RUNS



IMPROVED WIRING PROTECTION

## **Environmental Compliance**

The SSVEO has instituted many measures to keep the processing and maintenance of the orbiter fleet environmentally compliant. Four environmentally safe solvents were approved as alternatives to ozone-depleting Freon 113, and the orbiter primer was switched from a carcinogenic chromated paint to a non-chromated alternate. The project continues to develop alternative materials and processes intended for future implementation efforts. Other efforts in development include a water-based tube bending lubricant which does not require hazardous solvents to remove, and a non-chromated etch that prepares aluminum for bonding even better than the traditional chromated product. The SSVEO continues to make strides in processing the orbiters in a safe, environmentally compliant manner.



## Orbiter Upgrades

### Electric Auxiliary Power Unit (EAPU) Upgrade

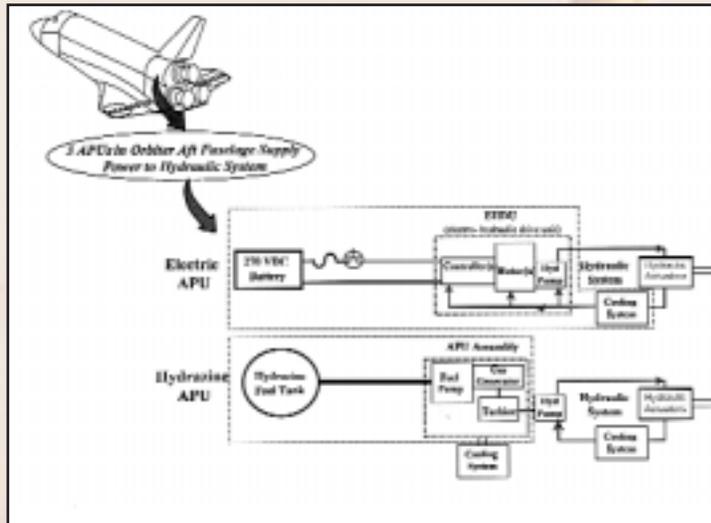
Today, hydraulic pressure required to operate the orbiter's various aerosurfaces, propulsion system valves, umbilical plate retractors and landing gear brakes is provided by three hydrazine auxiliary power units (HAPU). A quantitative risk assessment of the Space Shuttle performed in 1997 identified the HAPU as being responsible for approximately 30% of the overall catastrophic mission risk that could result in loss of crew and vehicle. Of this 30%, most of the risk is derived from circumstances caused by the highly toxic and flammable hydrazine fuel or the high-speed turbine of the current APU system.

An electrically powered concept is being evaluated to replace the three HAPUs using lithium-ion batteries as shown in the figure. The battery, which contains the six modules as shown in the figure, will also contain a 270-volt power, distribution and control system and a thermal management system.

The objectives of the new EAPU system are:

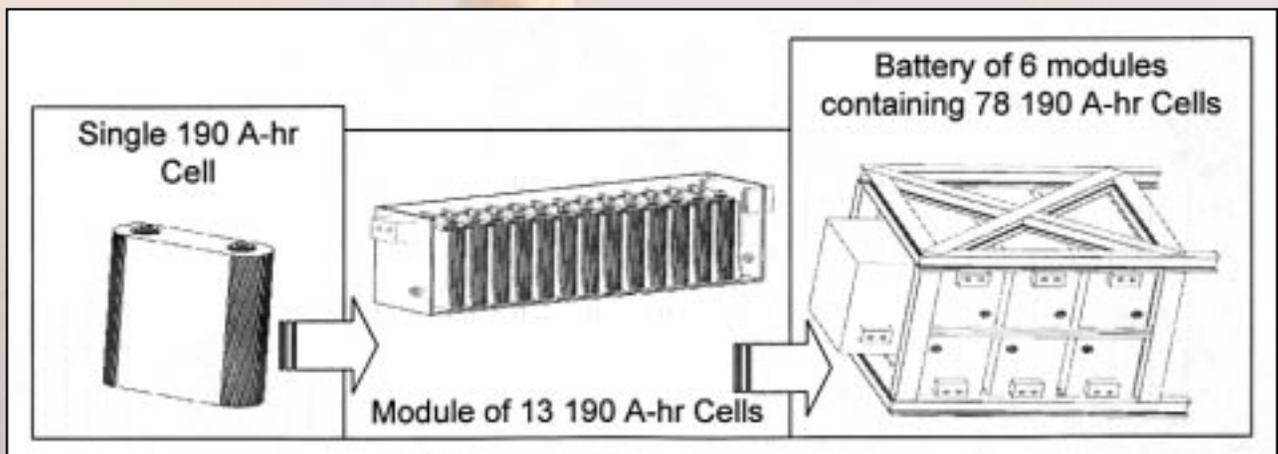
- Reduce APU contribution to orbiter catastrophic risk from 30% to less than 5%
- Reduce APU Criticality 1 items and hazards by more than 50%
- Increase APU system reliability by at least two orders of magnitude
- Reduce planned APU maintenance operations by more than 50%
- Provide an enhanced flow capability 30% higher than today's HAPU to support a single EAPU capability

Hamilton Sundstrand and Boeing Phantom Works have begun prototype development efforts on two proposed EAPU concepts with prototype hardware delivery in March 2001. The proposed Space Shuttle EAPU system will be the largest space-qualified, high-voltage, lithium-ion battery-powered system ever built.



EAPU UPGRADE CONCEPT

LITHIUM-ION BATTERY BUILDUP FOR EAPU



# JSC Space Shuttle Vehicle Engineering Office

## Cockpit Avionics Upgrade (CAU)

The CAU is a new orbiter upgrade initiative being pursued to support the flight safety goals and objectives of the SSP. This high-priority safety upgrade has completed significant project formulation activities this past year and is under development for first flight availability in 2005. The primary purpose of the CAU project is to improve the flight safety, reliability and operability of the Space Shuttle by upgrading the existing cockpit avionics systems.

To achieve these improvements, the objectives of the system upgrade are:

- Increase crew situational awareness
- Reduce crew workload
- Reduce crew training

Today, limitations of the existing cockpit avionics systems result in situations where the flight crew experiences excessive workload that adversely affects their situational awareness and impairs their ability to diagnose and isolate system failures (see original cockpit photo).



SAMPLE CAU DISPLAY

The CAU will introduce enhancements designed to mitigate these problems by providing improved flight and system display capabilities that will improve crew performance. Increasing the crew's

ability to manage information during critical flight operations will significantly benefit the overall safety and reliability of the Space Shuttle system.

The CAU project will implement new orbiter cockpit avionics hardware and software to meet the human-machine interface requirements being defined by the flight crew and operations communities. Orbiter cockpit displays and crew interface capabilities will be significantly improved by replacing the existing orbiter integrated display processors with higher performance command and display units. These will provide expanded performance to enable better display capability and access to information as well as the

implementation of new onboard software applications to enhance safety.

The new cockpit avionics hardware will have access to almost all vehicle data. This expanded data access facilitates the new capabilities to be provided by the CAU, which include:

- Improvements in onboard display and command capability
- Enable commanding from any multifunction display unit
- Improve vehicle status representation on displays
- Enable blending of vehicle information from all available onboard data sources
- Tailor information and commands according to flight phase and crew task status
- Improvements in system monitoring and control to reduce the number of crew actions necessary to access required displays
- Onboard logic improvements to provide enhanced caution and warning and root cause analysis of distributed system failures and other system failures that currently require significant crew workload to evaluate and resolve
- New onboard abort flight management software to provide the crew with real-time trajectory assessment and abort monitoring information

The CAU display enhancements together with new onboard software applications will dramatically increase the crew's ability to perform flight-critical functions while managing failures that could be encountered during the mission. A sample CAU display is shown in the figure.

ORIGINAL COCKPIT



The major focus of next year's efforts will be to complete the project implementation planning and initiate CAU hardware and software design and development activities. The five hardware prototyping teams, which include Ball Aerospace and Kaiser Aerospace, Boeing Reusable Space Systems and Seagr Engineering, Honeywell, Lockheed Martin and Orbital Sciences, will continue to work toward delivering prototype hardware that will be tested to demonstrate system performance capabilities. A single flight design will ultimately be down-selected from the candidate prototype designs that meets or exceeds crew operational safety objectives while optimizing power, weight, operating efficiencies and overall system reliability.

## **Main Landing Gear Tire and Wheel Assembly Upgrade**

One of the safety improvements initiated by the SSVEO is an upgrade to the main landing gear tire and wheel assembly. The upgrade is intended to add 20% additional load-carrying capability to the tire and wheel above the current certification of 142,500 pounds. The initial activities in 2000 and 2001 will be focused on the iterative process of tire design and testing that will result in a selection of the specific design for production in early 2002. The upgraded tire and wheel assembly, as seen in the picture, will be integrated into the Orbiter fleet in 2003. BF Goodrich and Michelin are the primary vendors supporting the upgrade effort for the wheel and tire, respectively.

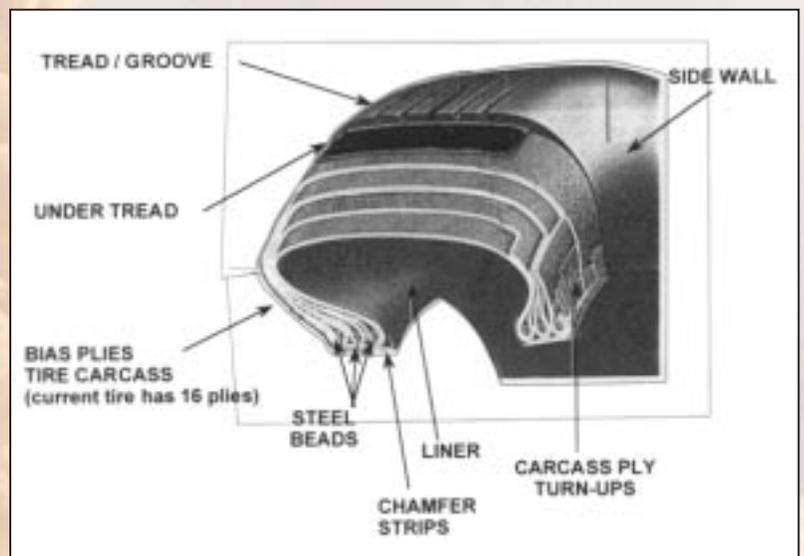
## **Long-Life Alkaline Fuel Cell (LLAFC) Upgrade**

The SSVEO has initiated a program to replace the orbiter's existing fuel cells with a LLAFC. As one of the Space Shuttle supportability upgrades, the primary purpose of the program is to double the time between fuel cell power-plant overhauls. Improvements to the power plant will be made to increase its operational life from 2,600 to 5,000 hours. This includes improvements to electrochemical cells and ancillary components. Its avionics will be modernized to include enhanced monitoring capability for all individual cell voltages and other key fuel cell parameters. This enhanced monitoring capability will be used for flight operations as well as for ground processing. It will also be compatible with future Space Shuttle

avionics upgrades. The current alkaline fuel cell has proven to be both safe and reliable. The LLAFC will meet all current fuel cell requirements in addition to those proposed for this upgrade, making fuel cell changes nearly transparent to the vehicle. The project, which began in February 2000, will design, fabricate and qualify the LLAFC with planned installation into the fleet beginning in 2004.

## **Crew Escape Study**

The Space Shuttle will continue to be the nation's only reusable manned launch system for the foreseeable future. As part of the Safety Upgrades Program, the SSP is investigating enhanced crew escape capability with the objective of making significant strides in reducing crew risk from failures that result in the loss of the orbiter. Past studies and crew escape system conceptual designs are being used as a starting point to identify crew egress systems that come closest to achieving NASA's goals. New technologies and concepts for orbiter crew escape systems are being incorporated into the study.



MAIN LANDING GEAR TIRE UPGRADE



# JSC Mission Operations Directorate



Randy Stone  
Director  
Mission Operations

## Mission Operations Directorate (MOD) Space Shuttle Cockpit Council

Initiated in 1999, the Space Shuttle Cockpit Council (SSCC) was formed through joint leadership collaboration between MOD and the Flight Crew Operations Directorate (Astronaut Office). The SSCC is responsible for providing cockpit

user interface requirements and prioritizations of cockpit upgrade projects to the Space Shuttle Program (SSP). MOD has served as the lead for technical and training core competencies for the team, in addition to providing joint council leadership and the prototyping laboratory. Although the assessment of the current cockpit reflected a safe operation, the team identified several areas of improvement in situational awareness and reduction in crew workload that would benefit crew operations and training. The support of MOD and the Astronaut Office are an essential ingredient in the development of Cockpit Avionics Upgrade requirements and the successful progression to flight implementation.

## The Neutral Buoyancy Laboratory (NBL)

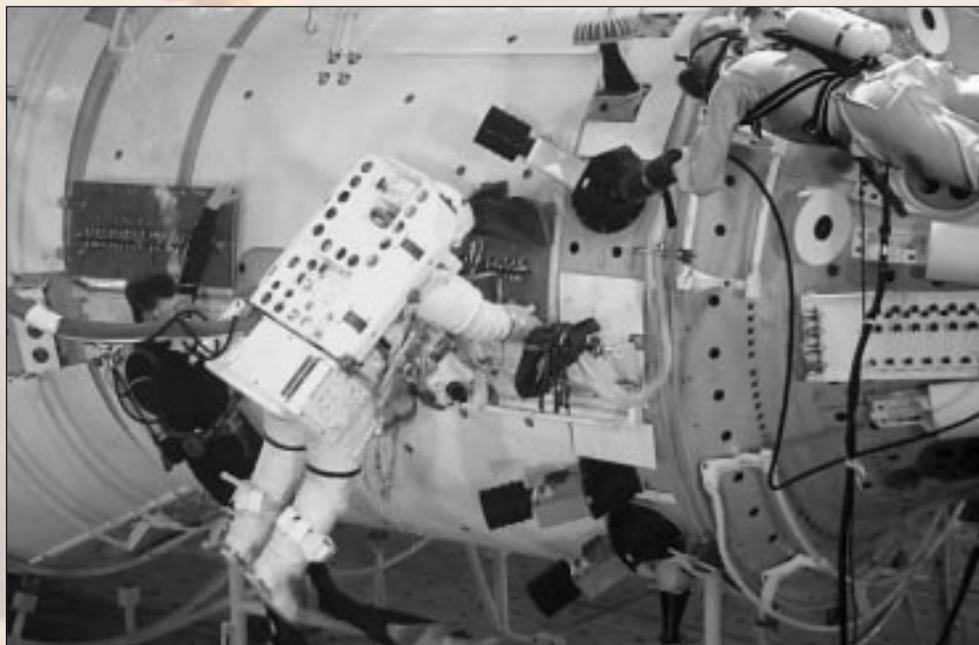
The NBL is a world class facility providing zero gravity EVA simulation training required to support SSP missions such as the Hubble Space Telescope and the assembly of the ISS. The NBL provides year-round astronaut training, engineering development, flight procedure development, and real-time mission support.

The primary mission of the NBL is the preparation of astronauts for SSP and ISS missions involving EVA. A talented cadre of multidisciplined, highly-trained personnel support all NBL EVA training sessions. Technical specialties and professional services provided by the NBL include mechanical,

electrical, ocean and marine engineering, control systems experts, robotics specialist, facility operations and maintenance personnel, and safety engineering.

The 6.2-million-gallon NBL tank has the capacity to accommodate full-scale, high-fidelity, in-water mockups and trainers for both the SSP and the ISS Programs. Measuring 202 feet long by 102 feet wide by 40 feet deep, the tank enables astronaut training to ensure on-orbit performance via use of facility unique teams, processes, methods and tools. All critical NBL processes are ISO-9001 compliant including EVA training, daily operations, sustaining engineering and maintenance.

### NEUTRAL BUOYANCY LAB MISSION TRAINING





David A. King  
Shuttle Processing (KSC)

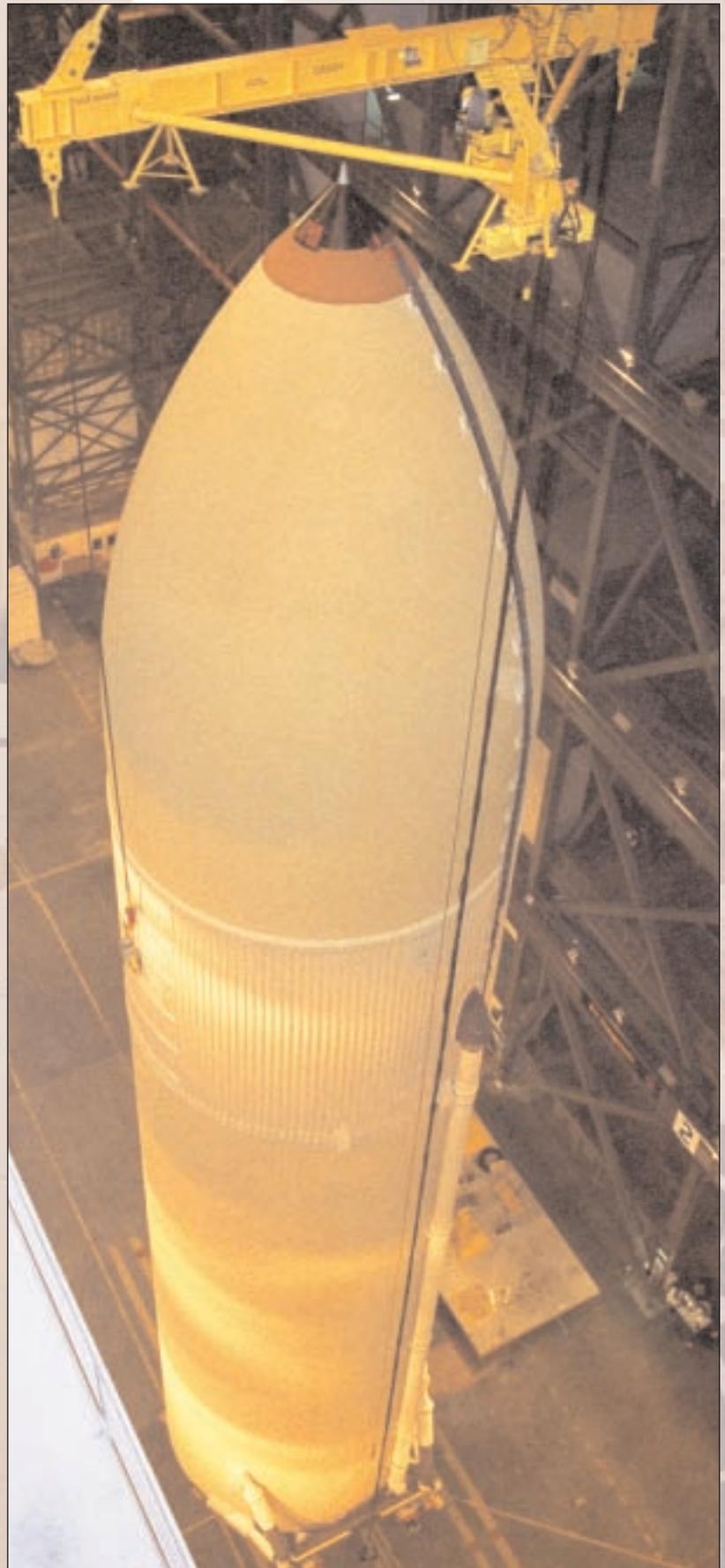
## External Tank (ET) Weighing Process Enhancements

A more precise method of weighing the new SLWT was needed to meet the tight tolerances imposed by the new design. A team of KSC, MSFC, Lockheed Martin, and USA personnel was formed to develop an improved weighing method. The team developed and implemented a series of improvements that enabled the required weighing accuracy of the ~58,300 pound SLWT to within +/- 139 pounds. These improvements involved modifications to the lifting/weighing fixture (see figure) and improved sensors and procedures.

The weighing process was successful transferred to the MAF during the summer of 2000. Statistical process control and performance matrix methods were implemented at MAF as a safeguard to ensure actual weight accuracy. The SSP now receives a lighter, more accurately weighed ET earlier in the mission planning phase.

## Hazardous Gas Detection of Orbiter Aft Fuselage T-O Umbilicals

A multidiscipline NASA/contractor team recorded and analyzed displacement and temperature measurements on the liquid hydrogen T-O umbilical carrier plates. This was done to gain a better understanding of the performance of the aft hazardous gas quick disconnect that is used to measure hazardous concentrations of hydrogen in the aft compartment during launch countdown. This will allow a better understanding of the analyzer readings to avoid unnecessary and costly launch aborts.



# KSC Shuttle Processing

## Checkout and Launch Control System (CLCS)

The CLCS is being developed to replace the existing Launch Processing System used to launch the Space Shuttle. The CLCS provided its first operational support at the Hypergolic Maintenance Facility (HMF) at KSC in August 2000. The new system includes a modern control room with state-of-the-art consoles and new technology hardware and software with greatly expanded capabilities. At the HMF, the CLCS will be used initially for testing the forward reaction control system modules, providing full command, control and monitoring of the operations. Some of the capabilities of the new system include increased automation, more visual feedback of the actual condition of the flight hardware and ground support equipment and access to drawings, advisory tools and trending data. Following completion of the applications software for the aft propulsion system, the CLCS will be used exclusively at the HMF, currently scheduled for the summer of 2001.

The CLCS project will replace four other control systems including all the firing rooms in the Launch Control Center at KSC. The hardware was installed in the first operations control room and is being used to develop and test applications software. Multiple systems have been successfully integrated during simulated orbiter power-up tests. The CLCS project continues to develop the additional system and applications software needed to support Space Shuttle processing at the three orbiter Processing Facilities (OPFs), the VAB and launch pads 39A and 39B.

## Shuttle Data Center (SDC)

The SDC represents a significant development project that was designed and implemented at KSC. The SDC, brought on line March 31, 1999, is responsible for recording and archiving Space Shuttle test data, providing SSP engineers with software data analysis tools, and building the firing room computer software loads. The new system is a distributed client server architecture based on standard hardware and software products. The system consists of over 80 high-performance servers connected by a high-speed redundant network. Standard products coupled with on-site vendor support agreements allow lower life cycle costs and improved supportability.

## Central Operations Facility (COF)

From 1983 to the present, Space Shuttle launch processing evolved as each new subsystem came on line. This was a natural evolution, but not necessarily a planned one. The current firing room computers are all stand-alone resources. No networking existed when these systems were designed and deployed. The processors were specially ordered from a single vendor, and the software environment was so optimized that just to change one line of code required many hours of analysis and testing.

The systems today are being designed and deployed using industry standard hardware and software components. High-speed networks are a necessity. Remote access is now provided via standard campus networks using tools capable of remote operation, integrated communications and maintenance.

The COF provides a central location designed to facilitate the operations of these round-the-clock support systems. What was once impossible is now mandatory. The COF is a state-of-the-art operation center, staffed with trained system experts. Using standard designs, systems like the SDC, the Record and Playback Subsystem, and the new CLCS can all be monitored and managed from a singular central location.



## Payload Ground Handling Mechanism (PGHM) Enhancements Project

The Pad 39B PGHM has been upgraded from a manual movement capability to an automated capability to allow personnel to process vertical payloads in a safer and more efficient environment. This new design has reduced critical items from 42 to 26. Pad 39A's PGHM will receive a similar upgrade during the next available window.

## Safe Haven

The Safe Haven project was successfully implemented and verified operational this year. The Safe Haven project maximizes protection capability of Space Shuttle flight hardware by providing short-term storage of a partially or fully stacked vehicle in High Bay 2 of the VAB. Implementation of the project increases operational flexibility by enabling vertical flight hardware processing operations to simultaneously proceed on all three Mobile Launch Platforms (MLPs) at any given time. With the successful completion of the project, the capability now exists to move a partially stacked or fully stacked Space Shuttle into High Bay 2 of the VAB while providing minimal disruption to vertical processing in VAB High Bays 1 and 3.

## Ground Systems Structures Modifications

Taking advantage of the reduced launch rate this year, KSC personnel implemented numerous upgrades, modifications, and major refurbishment projects on various KSC ground systems in the Launch Complex (LC)-39 area. Modification and refurbishment schedule windows were defined for each launch pad. The window for LC-39B began after the launch of STS-103 in late 1999, and concluded for the STS-106 pad processing flow in late July 2000. The modification window for LC-39A began following the STS-101 launch in late May 2000, and concluded in mid August 2000 before the



PAYLOAD GROUND HANDLING MECHANISM



SAFE HAVEN AT THE VAB



# KSC Facility Enhancements

STS-92 flight hardware arrived at Pad 39A. Grounds systems major modification and refurbishment projects on the launch pads include the following:

## Pad 39B

- Crawler path surface refurbishment
- 9099 Interface Tower refurbishment
- Rotating Service Structure drive truck gearbox overhaul
- Side flame deflector wheel assembly replacement
- Pad slope repair
- Hinge column crossover safety enhancements
- Numerous safety tie-off enhancements
- Main flame deflector structural refurbishment

## Pad 39A

- Orbiter weather protection wall refurbishment
- Fixed Service Structure elevator cab modifications
- Rotating Service Structure drive truck gearbox overhaul
- Numerous safety tie-off enhancements
- Side flame deflector wheel assembly replacement
- Corrosion control on liquid oxygen storage sphere

Also during this extensive modification and refurbishment period, a corrosion control project was implemented on MLP-1 at the MLP refurbishment site. This project was the most comprehensive corrosion control effort performed on any MLP in several years.



# Space Shuttle Annual Report







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